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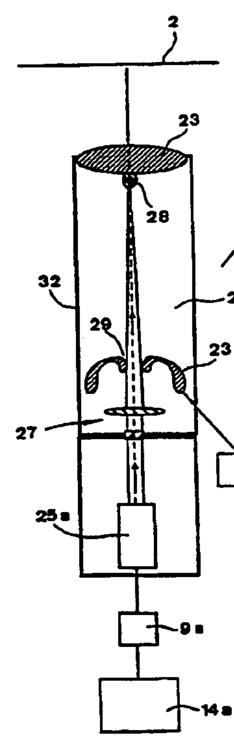
(54) Title: SWITCHING DEVICE INCLUDING SPARK GAP FOR SWITCHING ELECTRICAL POWER


(57) Abstract

A device for switching electric power comprises at least one electric switching arrangement (5). This switching arrangement comprises at least one switching element (10a) comprising an electrode gap (24). This gap is convertible between an electrically substantially insulating state and an electrically conducting state. Furthermore, the switching element comprises means (25) for causing or at least initiating the electrode gap or at least a part thereof to assume electrical conductivity. The means (25) for causing or at least initiating the electrode gap to assume conductivity are adapted to supply energy to the electrode gap in the form of radiation energy to bring the gap or at least a part thereof to the form of a plasma by means of this radiation energy.

# SWITCHING DEVICE INCLUDING SPARK GAP FOR SWITCHING ELECTRICAL POWER.

## FIELD OF THE INVENTION AND PRIOR ART

This invention is related to a device according to the pre-characterising part of enclosed claim 1. The device according to the invention may be used in any connection for switching purposes. Particularly preferred are applications where high power is to be switched. In reality, high voltage connections and electric power transmission applications are involved. A preferred, but not restricting, application of the device according to the invention is to protect, in an electrical power plant, an electrical object from the consequences of faults, primarily as far as current is concerned but also voltage. Besides, the invention comprises a method for protection of the object.

The electric object in question may be of arbitrary nature as long as it is contained in an electric power network and requires protection against fault-related over-currents, i.e. in practice short-circuit currents. As an example, it may be mentioned that the object may be formed by an electric apparatus having a magnetic circuit, e.g. a generator, transformer or motor. Also other objects may be in question, e.g. power lines and cables, switch gear equipment etc. The present invention is intended to be applied in connection with medium and high voltage. According to IEC norm, medium voltage refers to 1-72,5 kV whereas high voltage is >72,5 kV. Thus, transmission, sub-transmission and distribution levels are included.

In prior power plants of this nature one has resorted to, for protection of the object in question, a conventional circuit-breaker (switching device) of such a design that it provides galvanic separation on breaking. Since this circuit breaker must be designed to be able to break very high currents and voltages, it will obtain a comparatively bulky design with large inertia, which reflects itself in a comparatively long break-time. It is pointed out that the over-current primarily intended is the short-circuit current occurring in connection with the protected object, for instance as a consequence of faults in the electric insulation system of the protected object. Such faults means that the fault current (short-circuit current) of the external network/equipment will tend to flow through the arc. The result may be a very large breakdown. It may be mentioned that for the Swedish power network, the dimensioning short-circuit current/fault-current is 63 kA. In reality, the short-circuit current may amount to 40-50 kA.

A problem with said circuit-breaker is the long-break time thereof. The dimensioning break-time (IEC-norm) for completely accomplished breaking is 150 milliseconds (ms). It is associated to difficulties to reduce this break-time to less than 50-130 ms depending upon the actual case. The consequence thereof is that when there is a fault in the protected object, a very high current will flow through the same during the entire time required for actuating the circuit-breaker to break. During this time the full fault current of the external power network involves a considerable load on the protected object. In order to avoid damage and complete breakdown with respect to the protected object, one has, according to the prior art, constructed the object so that it manages, without appreciable damage, to be subjected to the short-circuit current/fault current during the break-time of the circuit breaker. It is

pointed out that a short-circuit current (fault current) in the protected object may be composed of the own contribution of the object to the fault current and the current addition emanating from the network/equipment. The own contribution of the object to the fault current is not influenced by the functioning of the circuit-breaker but the contribution to the fault current from the network/equipment depends upon the operation of the circuit breaker. The requirement for constructing the protected object so that it may withstand a high short-circuit current/fault current during a considerable time period means substantial disadvantages in the form of more expensive design and reduced performance.

As pointed out hereinabove, the invention is, however, not only restricted to protection applications. In other switching situations it is a disadvantage to have to resort to rather costly and bulky switching devices when high power is involved, for instance banks of semiconductor components, in order to manage the switching function aimed at. Today's semi-conductor component, which preferably is produced in silicon even if other materials may be in question, has for practical reasons a restriction as to the maximum electric field strength which the component may withstand before an electrical breakthrough occurs in the semi-conductor material. This implicates immediately corresponding restrictions of the maximum electric voltage that the component may be subjected to. In particular in high voltage connections, one is therefore forced to couple in series (stack) a large number of semiconductor components in such a way that none of the components contained in the stack is subjected to a voltage which is above a safe level for the component.

Furthermore, complications may occur in the design of the semi-conductor component in that the semi-conductor mate-

rial in itself endures to be subjected to, for instance compared with atmospheric air, very high electric field strength. The same is, however, not valid for the insulating material which necessarily must be present between those electrodes externally of the semi-conductor material between which the high voltage is placed. This also involves a restriction: In design of a semi-conductor component for high voltage use a careful balancing must be made between the electrical field strength in the semi-conductor material and the electric resistance in the surrounding insulating medium.

In several applications in electric power plants the components included therein are subjected to not only high electrical voltages but also to large electrical currents. When a current passes through a component having a certain resistance, considerable amounts of thermal energy (so-called Joule heat energy) which is proportional to the resistance in question and to the square of the current. Since each semi-conductor component has a small but negligible resistance, the maximum current that the component stack may endure is restricted. If very large currents are to be conveyed by the semi-conductor components one is forced to convey the current through several identical parallel current paths. The number of semi-conductor components increases, accordingly, multiplicatingly.

At high voltages and at large currents, a large number of semi-conductor components must be used. This results immediately in a lower reliability since all components must function in order to make the electric power plant, such as for instance a HVDC valve, to be in operation.

The fact that a large number of semi-conductor components are stacked means that they must be controlled with very high precision in time. Erroneous "timing" could for in-

stance result in a far too high a voltage being applied over an individual component causing a certain failure and appendant removal from operation of the entire plant. The "timing" problem increases, of course, if a plurality of parallel current paths must be provided and synchronized.

OBJECT OF THE INVENTION

The primary object of the present invention is to provide a switching device better suited for switching high electric power in a rapid manner and to a comparatively low cost than switching devices used today.

A secondary object of the present invention is to devise ways to design the device and the method so as to achieve better protection for arbitrary objects and, accordingly, a reduced load on the same, a fact which means that the objects themselves do not have to be designed to withstand a maximum of short-circuit currents/fault currents during relatively long time periods.

SUMMARY OF THE INVENTION

According to the invention, the switching arrangement is designed in accordance with the characterizing part of claim 1. Since the electrode gap of the switching means is brought to an electrically conducting state by supplying energy directly to the electrode gap proper in the form of radiation in order to establish ionisation/plasma in the electrode gap, conditions are created for a very rapid operation of the switching arrangement according to the invention. The ionisation/plasma in the electrode gap causes/initiates an electrically conducting plasma channel having a very high conductivity so that very large currents may be conveyed and this more specifically during relatively prolonged time pe-

riods without negative effects, which is in direct contrast to conventional semi-conductor art.

According to the invention, the secondary object indicated above is achieved in that the switching arrangement in the form of an over-current reducing arrangement, which is actuatable for over-current reduction with assistance of an over-current conditions detecting arrangement, is connected to the electric power plant for protection of the object. The switching arrangement may, according to a preferred embodiment, form an over-current diverter for diverting over-currents to earth or otherwise another unit having a relatively low potential.

Thus, the invention is based upon the principle, as far as the protection aspect is concerned, to utilise a rapidly operating switch arrangement, hereinafter called switch means, which without effecting any real breaking of the over-current, nevertheless reduces the same to such an extent that the object under protection will be subjected to substantially reduced strains and accordingly a smaller amount of damages. The reduced over-current/fault-current means, accordingly, that the total energy injection into the protected object will be substantially smaller than in absence of the switch means according to the invention.

The solution according to the invention based upon a switch means implies a particularly advantageous fulfilling of demands which may be set up in order to achieve a satisfactory protection function. Thus, a very rapid triggering may be achieved by the switch means so that occurring fault-related over-currents with a very small delay in time will be diverted via the switch means as soon as the electrode gap has adopted an electrically conductive condition. It is pointed out that the term "triggering" in this connection means bringing the switch means into an electrically conducting

state. By means of the arrangement of the switch means, said switch means may easily be dimensioned to be able to conduct very large currents. In order to obtain a satisfactory protection function it is, namely, desirable that the current conducting channel, which is established through the switch means, has a very low resistance. This means the largest possible strain-relieving of the object, which is to be protected from fault-currents. Besides, a switch means according to claim 1 may with a small effort be caused to function with a particularly high triggering safety. The triggering must not, in order to divert occuring fault-currents as soon as possible, therefore fail in a critical situation. The switch means according to the invention gives on the other hand rise to the possibility to dimensioning in order to achieve a very high electric strength in a non-triggered condition. The probability for a spontaneous breakthrough is thus to be at a minimum. It is especially preferred to thereby use at least one laser for triggering.

Preferable developments with respect to a.o. the means for supplying radiant energy to the electrode gap are defined in the enclosed claims. According to one embodiment, the radiant energy is supplied to the electrode gap in two or more spots or areas for the purpose of achieving the highest possible certainty with regard to bringing the electrode gap to assume an electrically conducting state. According to one alternative the energy supply means may be designed to supply the radiant energy along an elongated area in the conduction path which is aimed at between the electrodes. According to an optimal embodiment this elongated area may, entirely or substantially entirely, bridge the gap between the electrodes. Although it is possible, in a case with two or more spots or areas for radiation supply, that these spots or areas are applied successively corresponding to the propagation with respect to the electrical conduction path between the electrodes in such a way that the spots or areas

are successively applied with a time delay, it is, according to the invention, normally preferred to apply these spots or areas substantially simultaneously for making the electrode gap conducting momentarily.

Furthermore, the means for supply of triggering energy may according to the invention be adapted to apply the radiant energy in a volume having a tubular shape. This is particularly preferable when one of the electrodes comprises an opening, through which the radiant energy is supplied, and when the radiant energy supplied in a tubular volume is applied relatively close to the electrode provided with an opening.

According to an alternative embodiment, the energy supply means may be designed to supply the radiant energy in a plurality of substantially parallel, elongated areas extending between the electrodes.

The radiant energy may also be supplied to the electrode gap transversely relative to an axis of the electrodes in one or more spots located between the electrodes.

The switching arrangement according to the invention may be used with advantage for realizing various switching functionalities obtainable conventionally by means of semi-conductor art. Expressed in other words, electrical components may be built by means of the switching arrangement according to the invention in suitable number, such electrical components having properties similar to those known per se within for instance semi-conductor art.

Further advantages and features of the invention, particularly with respect to the method according to the invention, appear from the following description and claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the enclosed drawings, a more specific description of an embodiment example of the invention follows hereinafter.

In the drawings:

| | |
|---|---|
| Fig 1 | is a purely diagrammatical view illustrating the basic aspect behind the solution according to the invention, |
| Figs 2a-2d | are diagrams illustrating in a diagrammatical form and in a comparative way fault current developments and the energy development with and without the device according to the invention; |
| Fig 3 | is a diagrammatical view illustrating a conceivable design of a device according to the invention; |
| Fig 4 | is a diagrammatical, detailed view illustrating a possible design of the over-current reducing arrangement, |
| Figs 5-7 | are views similar to Fig 4 of different variants, |
| Fig 8 | is a diagrammatical view illustrating an optical system for energy supply to the electrode gap; |
| Fig 9 | is a view illustrating an alternative optical system placed at the side of one of the electrodes; |
| Fig 10 | is a further alternative for an optical system arranged to supply the radiant energy around one of |

the electrodes and co-axially relative thereto without need for an opening in one of the electrodes;

Fig 11 is a view of an optical system based upon use of optical fibres;

Fig 12 is a principle view illustrating refraction of light emanating from a point source by means of a refractive axicone;

Fig 13 is a view similar to fig 16 but showing the action of the axicone on a collimated laser beam;

Fig 14 is a view illustrating the function of a refractive axicone for generation of an elongated focal area between the electrodes;

Fig 15 is a diagram illustrating the power density along the focal area in fig 18;

Fig 16 is a view similar to fig 18 but illustrating the use of a diffraction optical component;

Fig 17 is a view illustrating focusing in an elongated area by means of a reflective axicone;

Fig 18 is a view illustrating use of a diffractive axicone (a kinoform) capable of generating focal areas having different geometrical shapes;

Fig 19 is a diagrammatical view illustrating the device according to the invention applied in an electric power plant comprising a generator, a transformer and an electric power network coupled thereto;

Fig 20 is a view illustrating how energy may be supplied to the electrode gap transversely relative to an axis common to the electrodes, fig 20a illustrating radiant energy being supplied in a single spot or area whereas three such spots or areas occur in fig 20b;

Figs 21a and b are views illustrating how the radiant energy may be supplied such that several substantially parallel and electrically conducting channels are formed between the electrodes;

Fig 22 is a sideview illustrating an embodiment somewhat similar to the one in fig 10, it being apparent from

Fig 23 that a plurality of individual kinoforms (diffractive optical elements) are arranged around one of the electrodes.

Fig 24 illustrates in diagrammatical form that the switching arrangement according to the invention may fulfil a bidirectional triac function,

Fig 25 is a view illustrating a unidirectional triac function,

Figs 26-28 are three different examples on how bidirectional triac function may be achieved by means of switching arrangements according to the invention each comprising two switching means,

Figs 29a-d are views illustrating that the switching arrangement according to the invention by series coupling with one or more diode functionalities may be provided to function like a thyristor,

Figs 30 and 31 are examples on how switching arrangements according to the invention may be used with triac function or thyristor function, and

Fig 32 is a diagrammatical view of the switching arrangement according to the invention in a series switching function.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

An electric power plant comprising a protected object 1 is shown in Fig 1. This object could for instance consist of a generator. This object is connected, via a line 2, to an external distribution network 3. Instead of such a network, the unit denoted 3 could be formed by some other equipment contained in the electric power plant. The electric power plant involved is conceived to be of such a nature that it is the object 1 itself which primarily is intended to be protected against fault currents from the network/equipment 3 when there occurs a fault in the object 1 giving rise to a fault current from the network/equipment 3 towards the object 1 so that the fault current will flow through the object. Said fault may consist in a short-circuit having been formed in the object 1. A short-circuit is a conduction path, which is not intended, between two or more points. The short-circuit may for instance consist of an arc. This short-circuit and the resulting violent current flow may involve considerable damages and even a total break-down of the object 1.

It is already pointed out that with at least some types of protected electrical objects 1, short-circuit currents/fault currents harmful to the object in question may flow from the protected object towards the network/equipment 3. Within the scope of the invention, it is intended to be used for protection purposes not only for protection of the object from externally emanating fault currents flowing towards the object but also from internal fault currents in the object flowing in the opposite direction. This will be discussed in more detail in the following.

In the following, the designation 3 will, to simplify the description, always be mentioned as consisting of an external electric power network. However, it should be kept in mind that some other equipment may be involved instead of such a network, as long as said equipment causes violent current flows through the object 1 when there is a fault.

A conventional circuit breaker 4 is arranged in the line 2 between the object 1 and the network 3. This circuit breaker comprises at least one own sensor for sensing circumstances indicative of the fact that there is an overcurrent flowing in the line 2. Such circumstances may be currents/voltages but also other indicating that a fault is at hand. For instance, the sensor may be an arc sensor or a sensor recording short circuit sound etc. When the sensor indicates that the overcurrent is <u>over</u> a certain level, the circuit breaker 4 is activated for breaking of the connection between the object 1 and the network 3. The circuit breaker 4 must, however, break the total short circuit current/fault current. Thus, the circuit breaker must be designed to fulfil highly placed requirements, which in practice means that it will operate relatively slowly. In Fig 2a it is illustrated in a current/time-dia-

gram that when a fault, for instance a short circuit in the object 1, occurs at the time $t_{fault}$, the fault current in the line denoted 2 in Fig 1 rapidly assumes the magnitude $i_1$. This fault current $i_1$ is broken by means of the circuit breaker 4 at $t_1$, which is at least within 150 ms after $t_{fault}$. Fig 2d illustrates the diagram $i^2 \cdot t$ and, accordingly, the energy developed in the protected object 1 as a consequence of the short circuit therein. The energy injection into the object occurring as a consequence of the short-circuit current is, accordingly, represented by the total area of the outer rectangle in Fig 2d.

It is in this connection pointed out that the fault current in Figs 2a-c and the currents in Fig 2d represent the envelope of the extreme value. Only one polarity has been drawn out in the diagram for the sake of simplicity.

The circuit breaker 4 is of such a design that it establishes galvanic separation by separation of metallic contacts. Accordingly, the circuit breaker 4 comprises, as a rule, required auxiliary equipment for arc extinguishing.

According to the invention the line 2 between the object 1 and the switching device 4 is connected to an arrangement generally denoted 5. This arrangement may in general regard be designated as a switching arrangement. In the application shown, the switching arrangement has the function of an arrangement reducing overcurrents towards the apparatus. The arrangement is actuatable for overcurrent reduction with the assistance of an overcurrent conditions detecting arrangement within a time period substantially less than the break time of the circuit breaker 4. This arrangement 5 is, accordingly, designed such that it does not have to establish any galvanic separation. Therefore, conditions are created to very rapidly establish a current reduction without having to accomplish any total elimina-

tion of the current flowing from the network 3 towards the protected object 1. Fig 2b illustrates in contrast to the case according to Fig 2a that the overcurrent reducing arrangement 5 according to the invention is activated upon occurrence of a short circuit current at the time $t_{fault}$ for overcurrent reduction to the level $i_2$ at the time $t_2$. The time interval $t_{fault}-t_2$ represents, accordingly, the reaction time of the overcurrent reducing arrangement 5. Since the task of the arrangement 5 is not to break but only reduce the fault current, the arrangement may be caused to react extremely rapidly, which will be discussed more closely thereunder. As an example, it may be mentioned that current reduction from the level $i_1$ to the level $i_2$ is intended to be accomplished within one or a few ms after unacceptable overcurrent conditions having been detected. It is then aimed at to accomplish the current reduction in a shorter time than 1 ms, and preferably more rapidly than 1 microsecond.

As appears from Fig 1, the device comprises a further breaker generally denoted 6 and arranged in the line 2 between the circuit breaker 4 and the object 1. This further breaker is designed to break a lower voltage and current than the circuit breaker 4 and may, as a consequence thereof, be designed to operate with shorter break times than the circuit breaker. The further breaker 6 is arranged to break not until after the overcurrent from the network 3 towards the object 1 has been reduced by means of the overcurrent reducing arrangement 5 but substantially earlier than the circuit breaker 4. From that stated, it appears that the further breaker 6 should be coupled to the line 2 in such a way that it is the current reduced by means of the overcurrent reducing arrangement 5 which will flow through the further breaker and which, accordingly, is to be broken by means thereof.

Fig 2b illustrates the action of the further breaker 6. This breaker is, more specifically, designed to break at the time $t_3$, which means that the duration of the current $i_2$ reduced by means of the overcurrent reducing arrangement 5 is substantially delimited, namely to the time period $t_2$-$t_3$. The consequence is that the energy injection into the protected object 1 caused by a fault current from the network 3 is represented by the surfaces marked with oblique lines in Fig 2d. It appears that a drastic reduction of the energy injection is achieved. In this connection it is pointed out that since, according to a specific model, the energy increases with the square of the current, a reduction to one half of the current reduces the energy injection to a fourth. It is illustrated in Fig 2c how the fault current will flow through the arrangement 5.

The dimensioning of the arrangement 5 and the further breaker 6 is conceived to be carried out such that the arrangement 5 reduces the fault current and the voltage to be broken by means of the further breaker 6 to substantially lower levels. A realistic break time as to the further breaker 6 is 1 ms. However, the dimensioning should be made such that the breaker 6 is caused to break not until after the arrangement 5 having reduced the current flowing through the breaker 6 to at least a substantial degree.

It is illustrated in more detail in Fig 3 how the device may be realised. It is then pointed out that the invention is applicable in direct current (also HVDC = High Voltage Direct Current) and alternating-current connections. In the latter case, the line denoted 2 may be considered to form one of the phases in a multiphase alternating-current system. However, it should be kept in mind that the device according to the invention may be realised so that either all phases are subjected to the protection function ac-

cording to the invention in case of a detected fault or that only that phase or those phases where a fault current occurs are subjected to current reduction.

It appears from Fig 3 that the overcurrent reducing arrangement generally denoted 5 comprises an overcurrent diverter 7 for diverting overcurrents to earth 8 or otherwise another unit having a lower potential than the network 3. Thus, the overcurrent diverter may be considered as forming a current divider which rapidly establishes a short circuit to earth or otherwise a low potential 8 for the purpose of diverting at least a substantial part of the current flowing in the line 2 so that said current does not reach the object 1 to be protected. If there is a serious fault in the object 1, for instance a short circuit, which is of the same magnitude as the short circuit that the overcurrent diverter 7 is capable of establishing, it may be said that generally speaking a reduction to one half of the current flowing to the object 1 from the network 3 is achieved as a consequence of the overcurrent diverter 7 in case the fault is close to the latter. In comparison with Fig 2b, it appears, accordingly, that the current level $i_2$ illustrated therein and being indicated to amount to approximately half of $i_1$ may be said to represent the worst occurring case. Under normal conditions, the purpose is that the overcurrent diverter 7 should be able to establish a short circuit having a better conductivity than the one corresponding to the short circuit fault in the object 1 to be protected so that accordingly a main part of the fault current is diverted to earth or otherwise a lower potential via the overcurrent diverter 7. It appears from this that, accordingly, in a normal fault case, the energy injection into the object 1 in case of a fault becomes substantially smaller than that which is indicated in Fig 2d as a consequence of lower current level $i_2$ as well as shorter time span $t_2$-$t_3$. It

should be obvious that a certain protection is obtained also when a short-circuit, which has been established, has a somewhat lower conductivity than the one corresponding to the short-circuit fault in the object 1 to be protected.

It has been pointed out that the notation 8 not only includes earth but another unit with a lower potential than the network/equipment 3. It is thereby to be noted that the unit 8 possibly could be formed by another power network or another equipment included in the electric power plant, said equipment having a lower level of voltage than the one which is effective for the network/equipment 3, to which the object 1, which is to be protected, is connected.

The over-current diverter 7 comprises switch means coupled between earth 8 or said lower potential and the line 2 between the object 1 and the network 3. This switch means comprises a control member 9 and a switch member 10. This switch member is arranged to be open in a normal state, i.e. insulating in relation to earth. The switch member 10 may however be brought into a conductive state via the control member 9 in a very short time in order to establish current reduction by diversion to earth.

Fig 3 illustrates that an overcurrent conditions detecting arrangement may comprise at least one and preferably several sensors 11-13 suitable for detecting such overcurrent situations requiring activation of the protection function. As also appears from Fig 3, these sensors may include the sensor denoted 13 located in the object 1 or in its vicinity. Furthermore, the detector arrangement comprises a sensor 11 adapted to sense overcurrent conditions in the line 2 upstreams of the connection of the overcurrent reducing arrangement 5 and the line 2. As is also explained in the following, it is suitable that a further

sensor 12 is provided to sense the current flowing in the line 2 towards the object 1 to be protected, i.e. the current which has been reduced by means of the overcurrent reducing arrangement 5. In addition, it is pointed out that the sensor 12, as well as possibly the sensor 13, is capable of sensing the current flowing in the line 2 in a direction away from the object 1, for instance in cases where energy magnetically stored in the object 1 gives rise to a current directed away from the object 1.

It is pointed out that the sensors 11-13 do not necessarily have to be constituted by only current and/or voltage sensing sensors. Within the scope of the invention, the sensors may be of such nature that they generally speaking may sense any conditions indicative of the occurrence of a fault of the nature requiring initiation of a protection function.

In cases where such a fault occurs that the fault current will flow in a direction away from the object 1, the device is designed such that the control unit 14 thereof will control the further breaker 6 to closing, in case it would have been open, and, in addition, the overcurrent reducing arrangement 5 is activated such that the short circuit current may be diverted by means of the same. When, for example, the object 1 is conceived to consist of a transformer, the function on occurrence of a short circuit therein could be such that the short circuit first gives rise to a violent flow of current into the transformer, which is detected and gives rise to activation of the arrangement 5 for the purpose of current diversion. When the current flowing towards the transformer 1 has been reduced in a required degree, the breaker 6 is caused to break, but, controlled by means of the control unit 14, not earlier than leaving time for the energy, in occurring cases, magnetically stored in the transformer 1 to flow

away from the transformer 1 and be diverted via the arrangement 5.

Furthermore, the device comprises a control unit generally denoted 14. This is connected to the sensors 11-13, to the overcurrent reducing arrangement 5 and to the further breaker 6. The operation is such that when the control unit 14 via one or more of the sensors 11-13 receives signals indicating occurrence of unacceptable fault currents towards the object 1, the overcurrent reducing arrangement 5 is immediately controlled to rapidly provide the required current reduction. The control unit 14 may be arranged such that when the sensor 12 has sensed that the current or voltage has been reduced to a sufficient degree, it controls the breaker 6 to obtain operation thereof for breaking when the overcurrent is below a predetermined level. Such a design ensures that the breaker 6 is not caused to break until the current really has been reduced to such a degree that the breaker 6 is not given the task to break such a high current that it is not adequately dimensioned for that purpose. However, the embodiment may alternatively also be such that the breaker 6 is controlled to break a certain predetermined time after the overcurrent reducing arrangement having been controlled to carry out current reduction.

The circuit breaker 4 may comprise a detector arrangement of its own for detection of overcurrent situations or otherwise the circuit breaker may be controlled via the control unit 14 based upon information from the same sensors 11-13 also controlling the operation of the overcurrent reducing arrangement.

It is illustrated in Fig 3 that the further breaker 6 comprises a switch 15 having metallic contacts. This switch 15 is operable between breaking and closing positions by

means of an operating member 16, which in turn is controlled by the control unit 14. A shunt line 17 is connected in parallel over this switch 15, said shunt line comprising one or more components 18 intended to avoid arcs on separation of the contacts of the switch 15 by causing the shunt line 17 to take over the current conduction from the contacts. These components are designed so that they may break or restrict the current. Thus, the purpose is that the components 18 normally should keep the conduction path in the shunt line 17 interrupted but close the shunt line when the switch 15 is to be opened so that accordingly the current is shunted past the switch 15 and in that way arcs do not occur or possibly occurring arcs are efficiently extinguished. The components 18 comprise one or more associated control members 19 connected to the control unit 14 for control purposes. According to one embodiment of the invention, said components 18 are controllable semiconductor components, for instance GTO thyristors, having necessary over-voltage arresters 30.

A disconnector 20 for galvanic separation in the current conduction path created by means of the shunt line 17 to the object 1 to be protected is arranged in series with said one or more components 18. This disconnector 20 is via an operating member 21 controlled by the control unit 14. The disconnector 20 is illustrated in Fig 3 as being placed in the shunt line 17 itself. This is of course not necessary. The disconnector 20 could also be placed in the line 2 as long as it ensures real galvanic separation, by series coupling with said one or more components 18, in the conduction path established by means of said series coupling so that accordingly there is not any possibility for current to flow through the components 18.

The device as it has been described so far operates in the following manner: In absence of a fault, the circuit

breaker 4 is closed just like the switch 15 of the further breaker 6. The components 18 in the shunt line 17 are in a non-conducting state. The disconnector 20 is closed. Finally, the switch means 10 of the overcurrent reducing arrangement 5 is open, i.e. it is in a non-conducting state. In this situation the switch means 10 must, of course, have an adequate electrical strength so that it is not inadvertently brought into a conducting state. Overvoltage conditions occurring in the line 2 as a consequence of atmospheric (lightning stroke) circumstances or coupling measures may, accordingly, not involve the voltage strength of the switch means 10 in its non-conducting state to be exceeded. For this purpose it is suitable to couple at least one over-voltage arrester 22 in parallel with the switch means 10. In the example such over-voltage arresters are illustrated on both sides of the switch means 10. Accordingly, the over-voltage arresters have the purpose to divert such overvoltages which otherwise could involve a risk for inadvertent breakthrough in the switch means 10.

The over-voltage diverters 22 are illustrated in Fig 3 to be connected to the line 2 itself on either sides of the connection of the switch means 10 to the line. It is in principle desirable that at least one over-voltage diverter has its connection as close as possible upstreams in relation to the switch means 10. The over-current diverters 22 could instead, which is indicated in Fig. 3 with the dotted lines 26 be connected to the branch line forming electric connection between the switch means 10 and the line 2. Such a construction enables integration of the switch means 10 and at least one over-voltage diverter 22 to one single electric apparatus, which apparatus may be brought in electric conducting connection with the line 2 via one single connection.

When an over-current state has been registered by means of some of the sensors 11-13 or the own sensor (it is of course realized that information from the own sensor of the circuit breaker 4 may be used as a basis for control of the over-current reducing arrangement 5 according to the invention) of the circuit breaker 4 and this over-current state is of such magnitude that a serious fault of the object 1 is expected to be at hand, a breaking operation is initiated as far as the circuit breaker 4 is concerned. In addition, the control unit 14 controls the over-current reducing arrangement 5 to effect such reduction, and this more specifically by bringing, via the control member 9, the switch means 10 into an electrically conducting state. As described before, this may occur very rapidly, i.e. in a fraction of the time required for breaking by means of the circuit breaker 4, for what reason the object 1 to be protected immediately is liberated from the full short-circuit current from the network 3 as a consequence of the switch means 10 diverting at least an essential part, and in practice the main part, of the current to earth or otherwise a lower potential. As soon as the current, which flows towards the object 1 via the further breaker 6, has been reduced in a required degree, which can be established on a pure time basis by a time difference between activation of the switch means 10 and operation of the breaker 6, or by sensing of the current flowing in the line 2 by means of, for instance, the sensor 12, the operating member 16 of the switch 15 is, via the control unit 14, controlled to open the contacts of the switch 15. For extinguishing or avoiding arcs, the components 18, e.g. GTO thyristors or gas switches, are via the control members 19 controlled to establish conductivity of the shunt line 17. When the switch 15 has been opened and, thus, provided galvanic separation, the component 18 is again controlled to bring the shunt line 17 into a non-conducting state. In that way the current from

the network 3 towards the object 1 has been efficiently cut off. After having brought the shunt line 17 into a non-conducting state, galvanic separation may, in addition, be effected by means of the disconnector 20 by controlling the operating member 21 thereof from the control unit 14. When all these incidents have occurred, breaking by means of the circuit breaker 4 occurs as a last incident. It is important to note that the over-current reducing arrangement 5 as well as the further breaker 6 according to a first embodiment can be operated repeatedly. Thus, when it has been established by means of the sensors 11-13 that the circuit breaker 4 has been brought to cut off, the switch means 10 is reset to a non-conducting state and the switch 15 and the disconnector 20 are again closed so that when the circuit breaker 4 next time closes, the protection device is completely operable. According to another embodiment, it is, however, contemplated that the over-current reducing arrangement 5 may require exchange of one or more parts in order to operate again.

It is pointed out that according to an alternative embodiment of the invention, the component or components 18 could be brought into a conducting state as soon as the over-current reducing arrangement 5 has been brought into a closing state and this independently of whether the switch 15 possibly is not opened thereafter. The control of the components 18 could then, as described before, occur via the control unit 14 or, alternatively, by means of a control function involving a slavish following of the closing of the arrangement 5.

Fig 4 illustrates a first embodiment of the over-current reducing arrangement 5 with switch means denoted 10a. The switch means 10a has electrodes 23 and a gap 24 prevailing between these electrodes. The switch means as it has been

described so far has means 25a in order to trigger the electrode gap 24 to form an electrically conducting path between the electrodes. A control member 9a is arranged to control the operation of the members 25a via the control unit 14a. The means 25a are in the example arranged for causing or at least initiating the electrode gap to assume electrical conductivity by means of causing the gap or part thereof to form a plasma. It is thereby essential that the means 25a are capable of realising a very rapid supply of triggering energy to the electrode gap. It is thereby preferred that the triggering energy is supplied in the form of radiative energy, which in turn is capable of effecting ionising/initiating of plasma in the electrode gap.

The means 25a comprises according to a particularly preferred embodiment of the invention at least one laser, which by means of energy supply to the electrode gap causes ionising/forming of plasma in at least a part of the electrode gap.

It is preferred in accordance with the invention to supply, with the aid of one or several lasers or other means 25a, energy to the electrode gap 24 in such a way that the complete electrode gap will be ionised and brought to the form of a plasma respectively, approximately momentarily in such a way that also the complete gap 24 immediately is brought to electrical conductivity. In order to spare with and optimize the use of the (normally) restricted available laser energy/-effect, the means 25a may, in application of the invention, be arranged so that they can provide ionization/plasma formation in only one or more parts of the gap 24. In the embodiment according to fig 4, it is illustrated that the means 25a supply the radiant energy in one single spot or area 28. As will be described later, the invention also comprises application of the radiant energy in a plurality of spots or areas in the electrode gap, including

also on one of or both of the electrodes, or in one or more rodlike areas extending continuously or substantially continuously between the electrodes.

By connecting the switch means 10a between the line 2 and earth 8 (or another unit with lower potential) as is diagrammatically indicated in Fig 4, i.e. with one of the electrodes 23 connected to the line 2 and the other electrode connected to earth 8, there will be a voltage difference between the electrodes causing an electric field. The electric field in the gap 24 is intended to be utilised in order to convey or cause an electric breakdown between the electrodes as soon as the means 25a have been controlled to triggering, i.e. have given rise to ionising/forming of plasma in one or more parts of the electrode gap. The established ionising/forming of plasma will be driven by the electric field to shunt the gap between the electrodes in order to in this way give rise to a low-resistant electrical conductive channel, i.e. an arc between the electrodes 23. It is pointed out that the invention is not intended to be restricted to use in connection with occurence of such an electric field. Thus, the intention is that the means 25a should be capable of establishing electrical conduction between the electrodes also without such a field.

Due to the demand on the switch means 10a to close very rapidly for current diversion, it is thus desirable when only a restricted part, e. g. a spot like part of the gap is ionised that the switch means is dimensioned in such a way that the strength of the electric field in the gap 24 will be sufficiently high for safe closing. It is however on the other hand a desire that the switch means 10a should have a very high electric strength against breakdowns between electrodes in its isolating rest position. The strength of the electric field in the gap 24 should therefore be proportion-

ally low. This will on the other hand reduce the speed, with which the switch means may be caused to establish the current diverting arc between the electrodes. In order to achieve an advantageous relation between the desire for a safe trigging of the switch means and on the other hand high electric strength against undesired trigging, it is according to the invention preferred that the switch means is formed in such a way that regarding its complete operational environment the electric field in the gap 24 has a field strength which is not more than 30% of the field strength at which a spontaneous breakdown normally takes place, when the gap forms electric isolation. This causes a proportionally low probability of a spontaneous breakdown.

The strength of the electric field in the electrode gap 24 in its isolating state is suitably not more than 20% and preferably not more than 10% of the field strength at which a spontaneous breakdown normally takes place. In order to on the other hand achieve an electric field in the electrode gap 24, which promotes forming of an arc at initiation of ionising/forming of plasma in a part of the electrode gap in a relatively rapid way, it is preferred that the strength in the electric field is at least 0,1% and suitably at least 1% ($E_4$), and preferably at least 5% of the field strength, at which a spontaneous breakdown normally takes place.

The electrode gap 24 is, as may be seen in Fig. 4, enlcosed in a suitable casing 32. A vacuum as well as a suitable medium in the form of gas or even fluid may for this purpose be present in the gap 24. In the case of a gas/fluid the medium in the gap is intended to be formed in such a way that it might be ionised and brought to plasma by trigging. It would in such a case be suitable to initiate ionisation/forming of plasma in the gap 24 at a point somewhere between the electrodes 23. It is however in Fig 4 illustrated the conceived case where there either is a vacuum or

a suitable medium in the gap 24. It is then preferred that initiation of closing takes place by way of making the laser 25a, which is illustrated in Fig 4, to focus the emitted radiative energy in at least one area 28 on or in the vicinity of one of the electrodes via a suitable optical system 27. This implies that the electrode will operate as an electron and ion emitter for establishing an ionised environment/a plasma in the electrode gap 24 in such a way that thus an arc will be formed between the electrodes. One of the electrodes 23 may according to Fig 4 have an opening 29, through which the laser 25a is arranged to emit the radiative energy to the area 28 with support of the optical system 27.

Fig 5 illustrates a variant 10b of the switch means, where instead the system laser 25b/optics 27b focus the radiative energy in a triggering area 28b, which is situated between the electrodes and in a medium between these electrodes. Plasma is accordingly, on triggering, intended to be developed from this area to bridging of the electrodes.

The variant 10c of the switch means in Fig 6 differs from the one in Fig 4 in the way that auxiliary electrodes 31 have been arranged between the electrodes 23c in this case, said auxiliary electrodes suitably being annular in a way that the beam emitted by the laser 25c may pass through the auxiliary electrodes 31. These electrodes are intended to operate for smoothing the electric field between the electrodes 23c and may be isolated from each other, i.e. they may be on a floating potential. The auxiliary electrodes result in improved safety against a spontaneous breakthrough, reduced dimensions of the switch means and a reduced sensitivity to the effect of external fields. The auxiliary electrodes may also be exposed to the laser beam/laser pulse and be made to emit free charges, which further promote the triggering capability.

Fig 7 illustrates a variant 10d of the switch means with the change that the electrodes 31d are added also here, in similarity to what has been described with the reference to Fig 6.

In order to achieve the above discussed relations regarding the field strength conditions between the electrodes 23 in the isolating state of the switch means, the characteristics of the switch means must of course be adequately adapted to the intended use, i.e. the voltage conditions which will arise over the electrodes 23. The constructive steps available regard of course forming of the electrodes, distance between the electrodes, the medium between the electrodes and the presence of possible further field affecting components between the electrodes.

Diffractive optical elements may be used with the invention. Diffractive optical elements are elements, in which the wave fronts of the light, which wave fronts determine the propagation of the light, are formed by means of diffraction rather than refraction. A particular type of diffractive optics modulates only the phase of the light and not the amplitude, for what reason components of this type has a very high transmittance. Pure phase modulation may be achieved by providing the surface of the optical component with a relief structure, where the relief height should be of the same order as the wavelength in order to achieve an optimum function of the component. An alternative way of achieving phase modulation is to modulate the refractive index of the optical element, which modulation is rather difficult. Diffractive optical elements may be manufactured by means of holographic technique, which does not admit that arbitrary functions may be realized. A more flexible manufacturing mode is computer generation, in which mode the optical function may be calculated in a computer. Entirely arbitrary optical functions may then, in principle, be realized, said func-

tions often being impossible to obtain by means of conventional refractive and reflective optics. The resulting face surface is thereafter transferred to a relief, e.g. by means of electron beam lithography or optical lithography, both of which are well known within the semi-conductor art. Such dator generated, phase controlling surface relief components are often called <u>kinoforms</u>. A well-known example is the Fresnell lens. This lens may, as all diffractive optics, be designed as a binary structure consisting of only two relief levels, or as a multilevel relief providing a substantially improved diffraction efficiency (functional efficiency of the optical element).

Fig 8 illustrates an embodiment based upon an optical system 27e comprising a lens system 35, via which arriving laser pulses are conveyed to a diffractive optical phase element 36, a kinoform. This element is designed to have a plurality of focal points or spots 28e generated starting from a single incoming laser pulse. These focal spots 28e are distributed along the axis of symmetry between the electrodes 23e. As a consequence of the focal spot 28e being distributed along a line between the electrodes 23e, a more safe establishment of an electrical conduction path between the electrodes is achieved, meaning as high a probability for triggering as possible at a voltage/electrical field strength as low as possible and with a time delay as short as possible.

The kinoform 36 is low absorbing and may, accordingly, resist extremely high optical energy densities. The kinoform is, accordingly, produced from a dielectrical material so that it will not disturb the electrical field between the electrodes in any serious degree.

In the embodiment according to fig 8, the radiant energy is supplied through an opening 29e in one of the electrodes as before. Fig 9 illustrates a variant where, generally speak-

ing, the only difference as compared to the embodiment according to fig 8 is that the diffractive optical element (kinoform 36f) is placed radially externally of one of the electrodes 23f. The optical element 36f is as before designed to deflect the laser light and focus the same in a number of spots or points distributed along the intended electrical conduction path between the electrodes. The bunches of beams forming the spots 28f have each their own deflection angle. Thus, the bunches of beams have to travel different distances to the respective spots 28f. The advantage in locating the kinoform 36f according to fig 9 at the side of one of the electrodes is that the kinoform will be located sidewardly of the strongest electrical field so that the field disturbance will be at a minimum. The electrode design is also simplified since no opening for the laser light is required.

Fig 10 illustrates an embodiment where a laser 25g supplies the laser radiation via an optical system 27g symmetrically in a number of focal spots or points 28g distributed along the length of the electrode gap without requiring any opening in the electrodes 23g. The optical system 27g comprises a prisma or beam divider 37 arranged to deflect the laser beam around the adjacent electrode 23g. Around this electrode 23g there is provided one or preferably more kinoforms 36g (diffractive optical elements) designed to focus, possibly by means of further lenses, the laser beam in the desired focal spot 28g so that plasma formations are generated in these spots.

Fig 11 illustrates a variant where a laser beam is conveyed by means of an optical system 27h comprising optical fibres 38 for formation of focal spots 28h located at various places between the electrodes 23h. The optical fibres 38 may be arranged to emit the light via lenses 39.

Fig 12 illustrates the basic principle of a conical lens, a so-called axicone. The definition of such an axicone may said to be every optical element having symmetry with regard to rotation and being capable of deflection of light by means of a refraction, reflection, diffraction or combinations thereof from a point source on the axis of symmetry of the element in such a way that the light intersects this axis of symmetry not in a single point as would be the case with a conventional spherical lens, but along a continuous line of points or spots along a substantial extent of this axis.

It is illustrated in fig 13 that collimated (non-divergent) light beams are deflected the same angle by the axicone. As a consequence of the symmetry as far as rotation is concerned, each beam will cross the axis of symmetry in some point.

It appears from fig 14 that the light may be focused in an elongated focal area 28i located between the electrodes 23i by means of an axicone 36i. This elongated focal area may according to one embodiment of the invention extend continuously all the way between the electrodes but could also adopt only a part of the gap therebetween. Fig 15 illustrates how the intensity is related to the distance between the electrodes. The full line curve illustrates the intensity distribution on illumination with the light beam which originally had a Gaussic intensity distribution whereas the dashed line curve illustrates the intensity distribution on illumination with a constant intensity distribution. For the rest, it is pointed out that the invention is not only restricted to such axicones which are purely linearly conical. Thus, axicones, the mantle surface of which deviate from the linear cone, which will have a direct influence on the focal intensity distribution, are included within the scope of the invention.

Fig 16 illustrates that a similar result as the one in fig 14 as far as the focal area 28k is concerned may be achieved by means of a diffraction optical element 36k, a kinoform.

Fig 17 illustrates that an elongated focal area 28m in the gap between electrodes 23m may be achieved by means of an axicone, more specifically a reflective axicone.

Fig 18 illustrates an embodiment where a particularly designed diffractive axicone 36n, a kinoform, has been designed to provide focal areas 28n and 28n' respectively having different shapes. In the example it is illustrated that the focal area 28n is elongated and arranged on the axis of symmetry of the axicone 36n and the electrodes. In contrast, the focal area 28n' has, as is indicated to the left in fig 18, obtained a tubular shape in cross-section. This tubular shape is advantageous most closely to an electrode 23n provided with an opening 29n since the periphery of the tubular focal area 28n' will be located relatively close to the electrode 29n provided with an opening. Both focal areas 28n and 28n' have, in fig 18, a substantially constant intensity along the axis of symmetry but perpendicular to this axis the intensity distribution, as far as the focal area 28n is concerned, is substantially Gauss-shaped or shaped in accordance with the Bessel function.

An advantage with an entirely or substantially conical or diffractive, co-axially focusing component as for instance in figs 8, 9, 10, 14, 16, 18 is that along the efficient direction of propagation of the radiant energy, said direction of propagation being a straight line, the plasma volume first formed, which occurs most closely to the electrode, at which the radiant energy is supplied, will not shield, reflect or to a serious degree affect the radiant energy focused in spots/areas being located further away from the

supply electrode. This "shadow effect" from the first formed plasma volumes could otherwise have hindered the radiant energy to efficiently reach later foci. This is a consequence of a plasma having the ability to be able to reflect or absorb radiant energy.

Fig 19 illustrates an embodiment where a generator 1b is connected to a power network 3a via a transformer 1a. The objects which are to be protected are therefore represented by the transformer 1a and the generator 1b. The over-current reducing arrangement 5a and the further breaker 6a as well as the ordinary circuit breaker 4a are apparently arranged in resemblance with what is evident from Fig 1 in the case that the object 1 in Fig 1 is conceived to form the object 1a according to Fig 19. It is therefore in this regard referred to the descriptions in connection to Fig 1. The same is true for the protection operation of the over-current reducing arrangement 5c and the further breaker 6c in relation to the generator 1b. The generator 1b should therefore in this case be equivalent to the object 1 in Fig 1 while the transformer 1a should be equivalent to the equipment 3 in Fig 1. The over-current reducing arrangement 5c and the further breaker 6c will therefore in combination with the conventional circuit breaker 4b be able to protect the generator 1b against a violent current flow in the direction from the transformer 1a.

Fig 19 also illustrates the further over-current reducing arrangement 5b with the associated further breaker 6b. Apparently, over-current-reducing arrangements 5a and 5b will therefore be arranged on either sides of the transformer 1a. It is to be noted that the further breakers 6a and 6b, respectively are positioned in the connections between said over-current reducing arrangements 5a and 5b and the transformer 1a. The further over-current reducing arrangement 5b is intended to protect the transformer 1a from violent cur-

rent flows towards the transformer from the generator 1b. The circuit breaker 4b will apparently be capable of breaking independently of in which direction between the objects 1a and 1b a safety function is desired.

Fig 20 illustrates diagrammatically how radiant energy may be supplied to the gap between electrodes 23o by means of one or more lasers 25o in one or more spots or areas 28o transversely relative to an axis X of symmetry between the electrodes 23o. By using a plurality of different lasers 25o, a very high power may be supplied to the gap between the electrodes for plasma formation.

Fig 21b illustrates that a plurality of substantially parallel, electrically conducting channels may be formed between the electrodes 23p. The view in fig 21a could be formed by a vertical view of fig 21b, in which case the electrically conducting channels, viewed from the side, is in one single row. However, it is possible to arrange a plurality of electrically conducting plasma channels in not only rows but also columns between the electrodes. The occurrence of a plurality of simultaneously electrically conducting channels increases the conducting capacity of the switch means.

Fig 22 illustrates a variant where the optical system 27q comprises an axicone (refractive or diffractive) dividing the radiation arriving from a laser or similar into parts and directing these radiation parts to diffractive elements (kinoforms 36q). These kinoforms are distributed about one of the electrodes, namely the one denoted 23q in fig 22. The same structure as in fig 22 is shown in perspective in fig 23. It appears in fig 23 that in the example 4 kinoforms 36q are arranged around the electrode 23q to cause the radiant energy to be focused by diffraction in a number of spots or areas 28q present along the axis of symmetry of the electrodes. The use of several discrete kinoforms 36q would ap-

pear to be more simple and non-expensive to realize than a continuously annular kinoform even if the latter wouldn't be impossible.

Semi-conductor components, such as thyristor, triac, GTO, IGBT and several others, are common in electric power systems of today, where they are used primarily as electronic valves to control, i.e. convey or block, the flow of electric current.

Even if semi-conductor components have a high efficiency, present good performance and have become relatively non-expensive by development of modern manufacturing methods, there are - primarily at very high electrical voltage levels - problems requiring complicated, bulky and cost requiring technical solutions.

By means of the technical embodiments/solutions presented in the present specification, alternatives to semi-conductor components are presented/explained, said alternatives providing more simple designs with considerably fewer components and to lower costs. Besides, the technique presented allows design of valve components which may endure considerably higher voltages than corresponding semi-conductor components. Besides, it is of fundamental weight that components based upon the technique presented herein may endure almost unrestricted electrical currents and current densities.

Within the electric power art semi-conductor elements are used in a large number of applications. This part of the electric power art usually is called power electronics. These applications are commonly denominated converters. A converter is an operative unit consisting of semi-conductor units (electronical valves) and necessary peripheral equipment used to change one or more of the characteristic vari-

ables and parameters of an electric power system. Thus, the converter may change voltage and current level, frequency and number of phases. Also electronic switches may be considered as converters.

As a converter (current redirector) also an apparatus interconnecting a DC-system with an AC-system is considered. In case the power flow is in a direction from the AC- to the DC-side, the converter operates as a rectifier. In case the power flow instead would occur in a direction from the DC-side to the AC-side, the converter operates as an alternator. An AC-AC-converter is dominated a frequency converter and converts an AC-signal to another AC-signal with an arbitrary relation between frequency, amplitude, phase and phase position as well as the number of phases of the voltage. A DC-DC-converter converts DC-voltage to another DC-voltage.

An electronical switch may be designed for AC or DC. It may be used for connection or disconnection of an apparatus or for controlling or checking active or reactive power.

An electronic valve is controllable if it can switch/change from a blocking state with a high voltage and a low current (off-state) to conducting state with a low voltage and a high current (on-state). The great efficiency of electronic converters depends upon this bistable function of the valves. A valve may either be stable in itself, such as a thyristor, or be controllable so as to operate bistably, such as a transistor.

The terminology is unfortunately not entirely consistent. An IEC-compilation can be found in "International Electrotechnical Dictionary" and in Publ. 60050-551 IEV, "Power Electronics". There is a very large number of different semiconductor components which entirely or partly may be replaced by the technique which is the subject matter of the

present patent application. Two examples of a presentation of the state of the art are "Modern Power Electronics" by Bose et al, IEEE Industrial Electronics Society, ISBN: 0-87942-282-3, and "Power Electronics - in Theory and Practice" of K. Thorborg, Chartwell-Bratt, ISBN: 0-86238-341-2. Among available semi-conductor components dealt with in these literature references the following should be mentioned:

-thyristor, diode, triac, GTO (gate turn-off thyristor), bipolar transistor (BJT), PWM-transistor, MOSFET, IGBT (insulated gate bipolar transistor), SIT (static induction transistor), SITH (static induction thyristor), MCT (MOS-controlled thyristor), etc.

I. A thyristor is turned-off (transferred to a blocking state) when its current is brought to zero by external means. In self-commutating alternators, the valves are turned-off by turn-off circuits consisting of condensators, inductors and resistors. The thyristor is the dominating semi-conductor component for high voltages and power levels.

The thyristor is defined as a semi-conductor component having a bistable function. It consists of three pn-transitions. It can be switched from off-state to on-state and vice versa in one or two directions. The most commonly used thyristor type is the so-called "reverse blocking triode thyristor". The thyristor has three connections: anode, cathode and gate. In absence of control pulse on the gate, the thyristor blocks the current flow in both directions. With an imposed voltage which is positive on the anode and negative on the cathode the thyristor is in its off-state and blocks the voltage. If the voltage imposed has an opposite polarity, the thyristor is in its reverse direction blocking state and reverse-blocks the voltage.

The leak currents in the reverse blocking and blocking states increase with the size of the thyristor and the temperature and may for very large thyristors be up to a few hundred of mA.

If the thyristor is triggered by imposing a current or voltage pulse on the gate, with adequate amplitude and duration, the thyristor switches from the off-state to the on-state and a current may flow in the forward direction from anode to cathode.

The voltage drop (the voltage over the thyristor) the so-called on-state voltage, is typically 1-2 Volt for normal values on the on-state current.

If the blocking (in forward direction anode to cathode) voltage exceeds the break over voltage specified for the thyristor, it changes spontaneously from the off-state to the on-state. This self-triggering voltage may seriously damage the thyristor and should, accordingly, never be exceeded.

In high voltage applications, where the system voltage substantially exceeds the maximum voltage that an individual thyristor element may endure, several thyristors must be coupled in series or cascade. In order to achieve an adequate voltage division between the thyristors coupled in series, each of them must be provided with an individual RC-circuit and with a resistive voltage divider: The RC-circuit acts as a transient voltage divider and the resistor divides the blocking and rearwardly blocking respectively voltages to approximately the same voltage difference per thyristor not withstanding the fact that different thyristors have different leak currents. Besides, the resistors make the voltages over the capacitors in th RC-circuits to be equally large. For thyristors connected in series it is of

the utmost importance that the triggering pulses of all thyristors are simultaneous and have identical amplitudes. Deviations from simultaneous triggering result in an over-voltage over the thyristor which is triggered (becomes conductive) as the last as a consequence of the current which will flow through the RC-circuit thereof and through the other thyristors. It is often required that only thyristors which have been matched to each other are used, i.e. have been selected to present performances adapted to the other thyristors, in particular in high frequency applications, a fact which complicates the structure and makes the same more expensive.

A triac is a bi-directional thyristor, which means that it has two blocking directions or forward directions. A triac is equivalent to two thyristors connected antiparallel and having a common gate. A triac is at the outset in its blocking state. Transfer to the on-state may, however, be controlled by a negative as well as a positive pulse on the gate and this may be achieved for both polarities over the triac. Technical performances for a triac corresponds in most cases with those of a thyristor having a corresponding size and performance. Restricting exceptions are caused by the triac not having equally short rise and fall times as a thyristor and not the same resistance to voltage transients (dU/dt) either. Therefore, they are mostly used in voltage regulators having a resistive load and for net frequencies, where rapid fluctuations in currents and voltages do not occur. A property of a triac to be bi-directional and only requiring one single cooling element as well as one single triggering pulse unit implies that simple and relatively non-expensive structures may be designed, in particular for low electrical power levels. Light triggered thyristors have, for natural reasons, a great interest for high voltages, as in HVDC-systems and in systems for thyristor switched phase compensating systems. The primary reason is

the high demands regarding electrical insulation. Besides, the risks are reduced that the thyristor fires/opens spontaneously as a consequence of noise coupled to its gate. Light pulses to the thyristor are transmitted via a light conductor to the thyristor from a control unit at earth potential. Since the light conductor is formed by di-electrical material, a high voltage insulation may be obtained.

However, the light energy which may be transferred by means of light conductors is restricted and there is a risk that the thyristor system obtains a long delay time for the control signal and, accordingly, an associated low increase rate of the on-state current of the thyristor unless the thyristor is equipped with a much more complex control structure comprising an amplification function for the signal finally applied on the gate of the thyristor. However, such a structure means that the thyristor again becomes more sensitive to noise which may be coupled via the gate and lead to inadvertent switchings. A laser triggered plasma switch may fulfil the same functions as a plurality of power semi-conductors and in some cases with very great technical and economical advantages as a result. In the present patent application the function of a laser triggered plasma switch as a triac is specifically dealt with. A laser triggered plasma switch, which is based on a momentary short- circuiting of a gasfilled electrode gap by means of an elongated, ionised and electrically conducting channel generated by the laser light has, primarily, the following great advantages:

The distance between the electrodes contained in the electrode system may be made large such that bigger problems do not occur in dimensioning and design of the external electrical insulation system. The structure is in that way considerably simplified and may be manufactured with lower costs.

Another advantage which is substantially greater is that there are in principle not any restrictions as to the maximum current which may be conducted by the plasma switch when it has been brought into its conducting state by the laser triggering. The conduction of the electrical current occurs through a laser light generated ionised channel which rapidly is developed to an arc. An arc is not subjected to any fundamental restrictions as far as the maximum current, which flows through the same, is concerned and there is, accordingly, not any maximum limit for the current density as is the case with semi-conductor components. When the current increases, the arc maintains an energetically advantageous current density by expanding radially. This self-adjusting function does not have any correspondence in a semi-conductor component.

A third fundamental advantage is formed by the fact that a plasma switch may be designed for very high voltage levels, and may then be constituted by only one single component. In comparison with a stacked semi-conductor structure having the same function and for the same high voltage level, this results in a considerably reduced complexity not only in the structure itself, which does not have to consist of a large number of accurately connected semi-conductor elements, but also in the drastically reduced demands on timing of these components relative to each other.

A substantially reduced number of active components in an application, compared to the corresponding application achieved with semi-conductor components, results in an increased reliability. Besides, reduced electrical losses, reduced device costs and less complicated control systems are achieved.

A further great advantage is that triggering may be carried

out very rapidly, in the order of some hundreds of microseconds, a fact which increases the possibility of precision modulation.

Triac function

Laser triggering in an elongated focal area allows for switching from the off-state to the on-state at an arbitrary point in time. By its construction, with an adequate combination of electrode distance, gas pressure, gas composition and the partial pressures of the part gases and the overall geometry of the encapsulating vessel, the plasma switch according to the invention presents properties identical to those of a triac. Without triggering, the plasma switch is present in its blocking, non-conducting off-state. This blocking property is bi-directional, i.e. the component is electrically insulating for voltages of both polarities over the plasma switch. On triggering, the plasma switch is transferred almost momentarily to its conducting on-state, in which it remains as long as the current in the arc is maintained above a certain design specific value, and as long as the voltage of the electrodes of the plasma switch are maintained above a certain, as well, design specific value. Also this conducting on-state is bi-directional: A plasma switch element may be made conducting for both polarities by the laser triggering. A switching arrangement with radiant energy triggering is diagrammatically illustrated in fig 24. A laser, for instance, may be used for the triggering. A switching arrangement 5 is triggerable on both polarities, which gives a bi-directional function.

Triac function with turn-off circuit

In an application the function of the switching arrangement must be completed with a possibility to shut off the switch, i.e. transfer it to the off-state. This is achieved by the

switch either (1) becoming automatically self extinguishing through its construction with an adequate combination of electrode distance, gas pressure, gas composition and partial pressures of the part gases or (2) the switch being given properties enabling external turn-off. In case (1) the time period after which self turn-off occurs may be checked and determined by the design of the structure. This self turning-off function may be realized for DC as well as AC systems. The AC case is a more simple case in that self turn-off automatically is assisted by the current through the conducting arc changing polarity, and, accordingly, passing through the current zero. In accordance with that stated hereinabove, conditions are created to efficiently turn-off the plasma switch in a manner which is entirely equivalent to those used for turning-off of a thyristor. Thus, the AC case places less stringent demands on the structure of the plasma switch. In case (2) the plasma switch may therefore be provided with external impedance elements, which assures that the on-state current is reduced to zero whereby the plasma switch is opened and assumes its off-state. The same effect may be achieved by using the operation circumstances in an AC system: Just before the current changes polarity in its passage through zero, the plasma switch is turned-off by itself as a consequence of insufficient ionisation of gas along the discharge channel. During the time it takes for the current to change polarity and for the new polarity to reach a voltage, for which the entirely ionised plasma channel again could be electrically conducting, a sufficiently large proportion of the plasma constituents has time to recombine to such a high degree that the conductivity of the channel becomes too low to support repeated turning-on of the arc. Thus, refiring is prevented and the plasma switch has assumed its off-state.

In contrast, the DC case involves more stringent demands on the structure of the plasma switch. By accurately balanced choice of design parameters, such as electrode distance and, primarily, total gas pressure, included gas components and the partial pressures thereof, these demands may, however, be fulfilled such that self turning-off may be achieved. A natural alternative is to allow the current to commutate to another line or component, the current in the plasma switch decreasing to zero and the plasma switch being turned-off. However, the most simple technical solution is to complete also the DC component with an external current restricting circuit element. A more coarse, but nevertheless efficient, solution is to couple in a suitable manner in connection with the plasma switch mechanical breakers, by means of which the plasma switch may be entirely separated from the network under voltage.

Unidirectional Triac function

A triac may conduct in two directions in its on-state. The plasma switch as it has been described here is in its nature primarily bi-directional since it does not have any type of diode function. If, however, the laser triggering is only effected during one of the two polarities of an AC system, the function becomes practically unidirectional, provided that the rests of plasma possibly remaining since the preceding triggering after recombination has a sufficiently low conductivity to resist a spontaneous triggering under the polarity (the half-period of the AC voltage) which is not laser triggered.

Fig 25 illustrates a plasma switch according to the invention with unidirectional triac function.

Bi-directional triac function with two plasma switch elements

An alternative to the embodiment described above is formed by two plasma switch elements having a turn-off function (self turning-off or external turning-off function) said plasma switch elements being connected anti-parallel between the higher and the lower potential. The two plasma switches, which now have been constructed and connected to the AC system to form two unidirectional units according to that stated hereinabove, are connected to the network and in relation to each other in such a manner that the current conducting directions of the two switches are opposite. Since the plasma switch in itself is bi-directional, this means that the two elements are designed to be laser triggered during their respective polarities, i.e. during a half period of its own, of the AC voltage. The two plasma switches may be triggered by one and the same laser, which requires the optical system to be provided with a light flux-controlling shutter. The laser is triggered at least two times per period and one time per half-period and the shutter may in one embodiment be designed so that the entire emitted light amount of the laser is alternatingly directed to one or the other of the two plasma switch elements. Such a light flux directing shutter may for instance be constituted by a rotatable highly reflecting mirror, which by reflection from its two end positions directs the laser light to each of the two light channels leading to the respective plasma switches. Another embodiment is to divide the laser light into two channels with an equal amount of laser effect in both channels. Each channel leads to one of the two plasma switches. A light flux-controlling shutter has been installed in each channel, said shutter ensuring, by controlled action at each triggering operation, that only one of the two plasma switch elements is subjected to the triggering laser light. The two plasma switch elements may also

very well be triggered by a laser for each plasma switch element, the operation of the lasers being controlled, checked and synchronized by an external electronic unit. Figs 26,27 and 28 illustrate the possibilities just described for forming bi-directional triac functions.

The same bidirectionality is of course also achieved with corresponding coupling of two plasma switch elements, which do not present self-turning-off function or which do not have been provided with external means for turning-off.

Thyristor functions

As already has been described in the prior art, the thyristor has a blocking state called off-state for voltages and currents in both directions. When the thyristor is triggered on its gate, it assumes its conducting state, denominated on-state, in which current may flow in the forward direction of the thyristor, but not in the opposite direction. A preferred manner of achieving the same function by means of a laser triggered plasma switch means that the laser triggered plasma switch is coupled in series with one or more diode functions, which may be of semi-conductor type. The number of diodes is entirely determined by the maximum voltage, which in an application in view may have to be placed over them. There are two different possibilities to orientate the diodes relative to the plasma switch: With the forward direction towards the plasma switch and with the forward direction directed away from the plasma switch. Accordingly, two different thyristor functions may be realized, where the resulting thyristor unit consisting of plasma switch in series with a number of diodes obtains different directionality or polarity. It is preferred that the diodes contained in such a constellation are equipped with individual RC networks or other more general impedance networks and a resistive voltage divider in order to efficiently achieve an

equalizing voltage division. The diodes are, accordingly, not subjected to different voltage levels, which could exceed their specified voltage resistance. Figs 29a-d illustrate that a plasma switch according to the invention may achieve different directionality or polarity by means of one or more diodes.

As an example on how the plasma switch described hereinabove may be used with a triac function or rather with a thyristor function reference is made to figs 30 and 31. The circuits presented in the figures act as change over switches. The function in fig 30 is as follows: The upper conductor $L_1$ is connected to an alternating voltage whereas the lower conductor $L_2$ is connected to earth or a lower potential. As long as the voltage in the upper conductor $L_1$ is positive without any of the plasma switches $PS_1$ and $PS_2$ having been triggered, no current may flow through the circuit. If, however, the plasma switch $PS_2$ is triggered to close, a current will flow through diode $D_1$ from the upper conductor $L_1$ to earth through $PS_2$. This current flows as long as the voltage has a positive polarity. After polarity change to negative polarity on the upper conductor $L_1$, a current would flow in the opposite direction. However, such a current may only flow after $PS_1$ having been triggered and it flows then from the upper conductor through the diode $D_2$ and $PS_1$ and the lower conductor through the diode $D_2$ and $PS_1$ to the upper conductor. Since the voltage drop over the diode $D_2$ may be made lower than the voltage drop over the arc in $PS_2$ in direction from $L_2$ towards $L_1$, the current will preferably flow through $D_2$ after the polarity change described instead of through $PS_2$. $PS_2$ may then not be refired spontaneously in wrong direction, and is accordingly left to rest during the present half-period with a negative polarity.

In the circuit just described the plasma switch is used in the function of a unipolar triac, i.e. generally a thyris-

tor. The circuit in fig 31 has been provided with two further diodes in series with the respective plasma switch, which entirely guarantees that the current after polarity change is not erroneously seeking to pass the plasma switch to be turned-off. Thus, the further diode prevents, as an example of an external means, this switch from refiring ("back firing").

It is considered to be obvious from the presentation given hereinabove that more technical functions than those here presented may be realized while using a laser triggered plasma switch as a starting point.

Fig 32 illustrates diagrammatically that a switching arrangement 5r is coupled in series in the line 2r previously discussed between the network 3r and the object 1r. The switching arrangement 5r comprises, suitably, a switch means 10r with the previously described character, i.e. a switch means having an electrode gap adapted to be brought into electrically conducting closing by means of radiant energy. However, this is not shown more closely in fig 32. As appears from fig 32, the switching arrangement 5r is intended to have a purely switching function, i.e. the feeding of the object 1r or possibly feeding in the opposite direction may occur via the switch means 10r when this is in a conducting state. When there is a need, the switch means 10r may be made to inhibit current passage relatively rapidly, e.g. for protection of the object 1r or possibly even the network 3r from current flow from the object 1d. In order to achieve switching-off by means of the switch means 10r in alternating current connections, it is sufficient that the means for energy supply to the electrode gap are caused to cease with such energy supply. On the following passage through zero, extinguishing of the arc in the switch means 10r is intended to take place so that the current feeding ceases. In direct current application, it is probably necessary to support the

turning-off function by taking measures to reduce or eliminate the voltage difference over the switch means 10r. Such means may consist in a switch 31 coupled parallel to the switch means 10r. Closing of the switch 31 means that the current is shunted passed the switch means 10r, a fact which causes the arc in the switch means 10r to be extinguished. In case such a measure wouldn't be sufficient, further switches could as a complement thereto be arranged on either sides of the switch means 10d in line 2r to totally disconnect the switch means 10r from the line 2r.

The purpose with fig 32 is to illustrate that the switch arrangement 5r according to the invention may find general switching applications, in which it may be the question of protecting various apparatus but also of switching power in various load situations in a more general sense.

It should be noted that the description presented hereinabove only should be considered as exemplifying for the inventive idea, on which the invention is built. Thus, it is obvious for the men skilled in the art that detailed modifications may be made without leaving the scope of the invention. As an example, it may be mentioned that according to the invention, it is not necessary to use a laser for supply of ionising/plasma forming energy to the gap 24. Also other radiative sources, for example electron guns, or other energy supply solutions may be applied as long as the rapidness and reliability demands according to the invention are fulfilled. It should be observed that the switch means 10 may according to the invention be applied for protection of electric objects against fault-related over-currents also in other operative cases than the ones illustrated in Figs 1, 3 and 19, where the device according to the invention is arranged in order to reduce the negative effects of the relatively slow breaking time of the circuit breaker 4. Thus, the switch means according to the invention does not neces-

sarily need to be operation-related to such a circuit breaker 4. It should finally be observed that the invention is well suited for alternating current as well as direct current.

Claims

1. A device for switching electric power comprising at least one electric switching arrangement (5), characterized in that the switching arrangement (5) comprises at least one switch means (10), which comprises an electrode gap (24), which is convertible between an electrically substantially isolating state and an electrically conducting state, and means (25) for causing or at least initiating the electrode gap or at least a part thereof to assume electrical conductivity and that said means (25) for causing or at least initiating the electrode gap to assume conductivity are adapted to supply energy to the electrode gap in the form of radiant energy to bring the gap or at least a part thereof to the shape of a plasma.

2. A device according to any preceding claim, characterized by said means (25) for causing or at least initiating the electrode gap or a part thereof to assume electrical conductivity comprising at least one laser (25).

3. A device according to any preceding claim, characterized in that the switch means (10) is formed in such a way that an electric field is present in its isolating condition between its electrodes (23), which field promotes or generates an electric flash-over between the electrodes on causing or initiating the electrode gap to assume electrical conductivity.

4. A device according to claim 3, characterized in that the electric field in the isolating condition of the electrode gap (24) has substantially less field strength than the field strength, at which a spontaneous breakthrough takes place.

5. A device according to claim 3 or 4, characterized in that the electric field in the insulating condition of the electrode gap (24) has a field strength which is not more than 30%, suitably not more than 20% and preferably not more than 10% of the field strength, at which a spontaneous breakthrough takes place.

6. A device according to any of the claims 3-5, characterized in that the electric field in the insulating condition of the electrode gap (24) has a field strength which is at least 0,1%, suitably at least 1%, and preferably at least 5%, of the field strength, at which a spontaneous breakthrough takes place.

7. A device according to any preceding claim, characterized in that the means (25) for causing or at least initiating the electrode gap (24) to assume electrical conductivity are arranged to supply the radiant energy in such a manner that the lowest electrical field strength, at which the electrode gap may be triggered to assume electrical conductivity, is minimized.

8. A device according to any preceding claim, characterized in that the means (25) for causing or at least initiating the electrode gap (24) to assume electrical conductivity are arranged to supply the radiant energy to the electrode gap in a such a manner that a time delay between the arriving radiant energy and a developed conductive ability of the electrode gap is minimized.

9. A device according to any preceding claim, characterized in that the switch means (10) and the means (25) for causing or at least initiating the electrode gap to assume electric conductivity are arranged such that the establishment of the electric conductivity in the electrod gap is substantially

independent of the electric field strength present between the electrodes of the switch means in its insulating state.

10. A device according to any preceding claim, characterized in that the means (25) for supplying triggering energy to the electrode gap are arranged to apply the radiative energy on or at least in the vicinity of at least one of the electrodes (23).

11. A device according to any preceding claim, characterized in that the means (25) for supplying triggering energy to the electrode gap are arranged to locate the radiative energy in one spot or area in the gap (24) between the electrodes (23).

12. A device according to any preceding claim, characterized in that the members (25, 27) for supplying the triggering energy to the electrode gap are arranged to apply the radiant energy in two or more spots or areas (28) between the electrodes.

13. A device according to claim 12, characterized in that the means for supplying triggering energy to the electrode gap are arranged to locate said two or more spots or areas of radiant energy along a line extending between the electrodes, said line corresponding to the extent of an electric conduction path desired between the electrodes.

14. A device according to any preceding claim, characterized in that the means (25) for supplying triggering energy to the electrode gap are arranged to apply the radiant energy in one or more elongated areas (28i,k, m, n), the longitudinal axes of which extend substantially along the direction of the electric conduction path which is intended between the electrodes.

15. A device according to claim 14, characterized in that the means (27) for supplying triggering energy to the electrode gap are adapted to shape the elongated focal area into a tubular shape.

16. A device according to claim 14 or 15, characterized in that the means for supplying triggering energy to the electrode gap are adapted to shape the elongated area so that it bridges, entirely or substantially entirely, the space between the electrodes.

17. A device according to any of claims 14 or 15, characterized in that the means (27) for supplying triggering energy to the electrode gap are adapted to form two or more elongated focal areas (28) in the electrode gap, said focal areas being located longitudinally after each other along the electric conduction path intended between the electrodes.

18. A device according to any of claims 1 and 10, characterized in that the means for supplying triggering energy to the electrode gap are adapted to apply the radiant energy on at least one of the electrodes as well as between them.

19. A device according to any of the claims 10-18, characterized in that at least one of the electrodes at the electrode gap has an opening (29), through which the means (25) for supplying triggering energy are arranged to direct the radiative energy.

20. A device according to claims 15 and 19, characterized in that the means (27) for supplying triggering energy to the electrode gap are adapted to locate the tubular radiant energy area (28) in the vicinity of that electrode which has an opening (29) and such that the axis of the tubular radiant energy area is substantially concentric to the axis of the opening in the electrode.

21. A device according to any preceding claim, characterized in that auxiliary electrodes (31, 31d) for equalizing the electric field and/or for active participation in the triggering process by said auxiliar electrodes being exposed to the radiant energy and, as a result, being capable of emitting free charges, are arranged at the gap (24) between the electrodes.

22. A device according to any of claims 10-21, characterized in that the means for supplying triggering energy to the electrode gap comprise a system for controlling electromagnetic wave energy.

23. A device according to claim 22, characterized in that the control system comprises at least one refractive, reflective and/or diffractive element.

24. A device according to claim 23, characterized in that the element is formed by an axicone.

25. A device according to claim 24, characterized in that the element is formed by a kinoform.

26. A device according to claim 23, characterized in that the elements comprise optical fibres (38).

27. A device according to any of claims 23-26, characterized in that the control system (27f, h) is located radially outwardly of the electrodes and adapted to direct bunches of rays towards the gap between the electrodes.

28. A device according to any of claims 23-27, characterized in that the control system (27g) is adapted to divide laser pulses into an annular configuration about one of the electrodes.

29. A device according to any preceding claim, characterized in that at least one over-voltage diverter (22) is connected in parallel to the switch means (10).

30. A device according to any preceding claim, wherein the electric object (1) is connected to an electric power network (3) or another equipment included in the electric power plant, the device comprising a switching device (4) in a line (2) between the object and the network/equipment, characterized in that the switch means (10) is connected to the line (2) between the object (1) and the switching device (4), and that the switch means (10) is actuatable for over-current diversion within a time period substantially shorter than the break-time of the switching device (4).

31. A device according to claim 30, characterized in that the switching device (4) is formed by a circuit breaker.

32. A device according to claim 21 or 31, characterized in that it comprises a further breaker (6) arranged in the line between the switching device (4) and the object, said further breaker being arranged between the switching means (10) and the object (1) and being adapted to break lower voltages and currents than the switching device (4) and therefore capable of performing a shorter break-time than the switching device and that the further breaker is adapted to break when the over-current towards or away from the object (1) has been reduced by means of the switch means (10) but substantially earlier than the switching device.

33. A device according to claim 32, characterized in that it comprises a control unit (14) connected to the detecting arrangement (11-13) and to the further breaker (6) in order to achieve actuation of the further breaker for breaking purposes when the over-current towards or away from the object

(1) is indicated, by means of the detecting arrangement, to be below a predetermined level.

34. A device according to any of the claims 32-33, characterized in that the further breaker (6) comprises a switch (15) over which there is coupled a shunt line (17) having one or more components (18) for avoiding arcs on separation of contacts of the switch (15) by causing the shuntline (17) to take over current conduction from the contacts.

35. A device according to claim 34, characterized in that said one or more components (18) in the shunt line (17) are closable into conduction by means of control via the control unit (14).

36. A device according to claim 34 or 35, characterized in that said one or more components (18) are formed by controllable semiconductor components.

37. A device according to any of the claims 34-36, characterized in that said one or more components (18) are provided with at least one over-voltage arrester (30).

38. A device according to any of the claims 34-37, characterized in that a disconnector (20) for galvanic separation is arranged in series with said one or more components (18).

39. A device according to claim 38, characterized in that the disconnector (20) is coupled to the control unit (14) to be controlled thereof for opening after the switch (15) having been controlled to have closed and said one or more components (18) having been placed in a condition for breaking the shunt line (17).

40. A device according to any preceding claim, characterized in that the protected object (1) is formed by an electric apparatus with a magnetic circuit.

41. A device according to claim 40, characterized in that the object is formed by a generator, transformer or motor.

42. A device according to any of the claims 1-41, characterized in that the object is formed by a power line, e.g. a cable.

43. A device according to any preceding claim, characterized in that two switch means (10) are arranged on either sides of the object to protect the same from two sides.

44. A device according to claim 1, characterized in that it comprises a control unit (14) connected to the switch means (10) and to the over-current conditions detecting arrangements (11-13), said control unit (14) being arranged to control the switch means to closing based upon information from the over-current conditions detecting arrangement when required for reasons of protection.

45. A device according to claim 44 and one or more of the claims 34, 36 and 40, characterized in that one and the same control unit (14) is arranged to control, based upon information from the over-current conditions detecting arrangement (11-13), the switch means (10) and the further breaker (6).

46. Use of a device according to any preceding claim for protection of an object against fault-related over-currents.

47. A device according to any preceding claim, characterized in that the means for supplying triggering energy to the electrode gap are adapted to focus the radiant energy in a

plurality of substantially parallel, elongated focal areas, the longitudinal axes of which are located substantially along the direction of the electrical conduction path aimed at between the electrodes (fig 21).

48. A device according to any preceding claim, characterized in that one or more switch means (10), possibly in addition to complementary diodes or other components, are arranged for forming switching or converter functionalities.

49. A device according to claim 48, characterized in that the functionalities are triac and thyristor functionalities.

50. A method in an electric power plant for protection of an electric object (1) from fault-related over-currents, characterized in that over-current diversion is accomplished by means of a switch means (10) when over-current conditions have been detected by means of an arrangement (11-13) for such detection, said switch means (10), which is arranged for diversion of over-currents to earth (8) or some other unit with a relatively low potential, being closed for over-current diversion by imparting an electrode gap (24), which is present in the switch means, electrical conductivity by supply of radiant energy to the electrode gap with the aid of triggering means (25).

51. A method according to claim 50, characterized in that a further breaker (6), which is arranged in a line (2) between a switching device (4) and the object (1) and between the switch means (10) and the object (1), is actuated for breaking after the over-current towards or away from the object (1) having been reduced by means of the switch means (10).

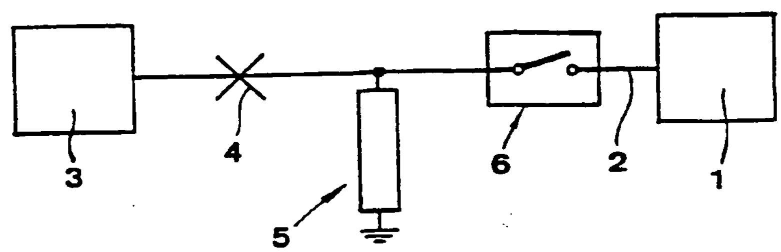



Fig 1

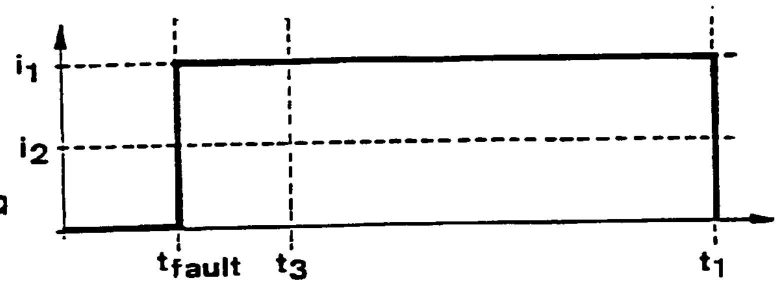



Fig 2a

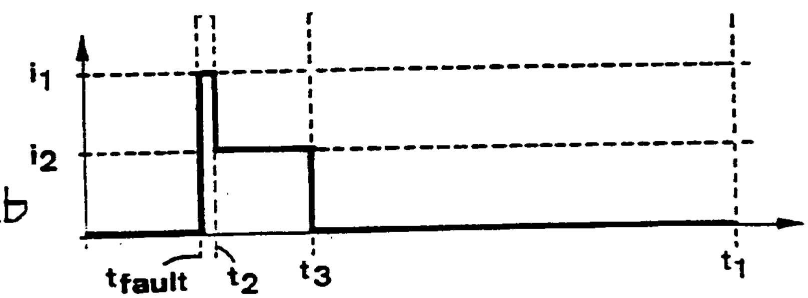



Fig 2b

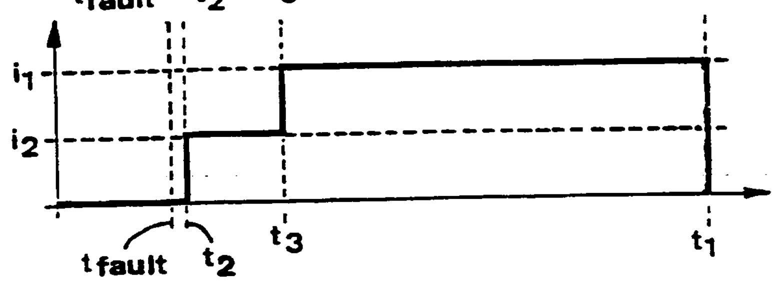



Fig 2c

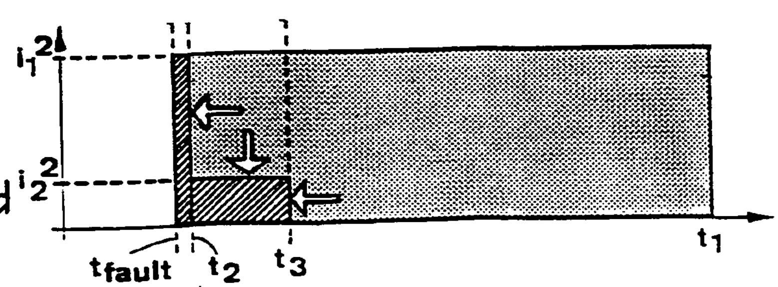



Fig 2d

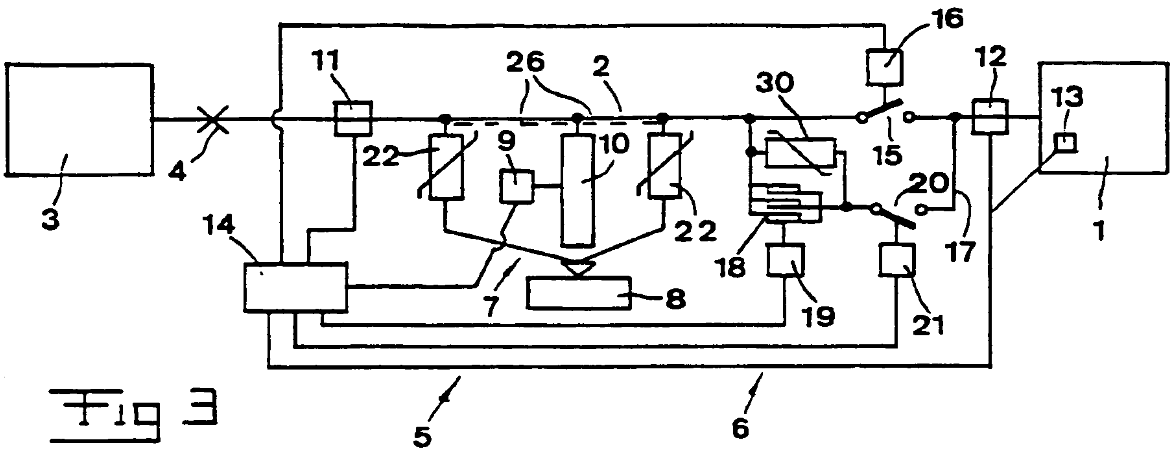

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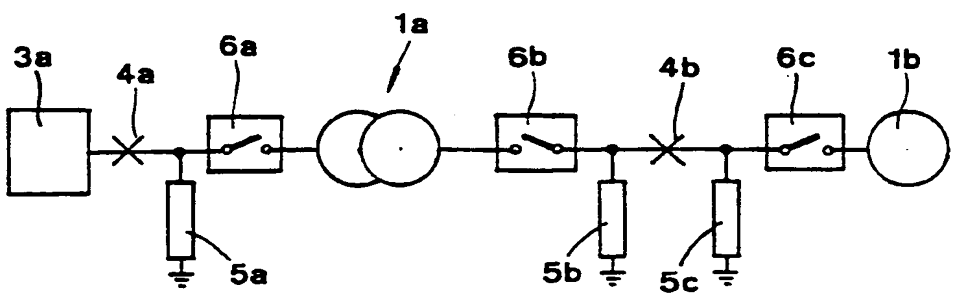
Fig 3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3a
4a
6a
6b
4b
6c
1b
5a
5b
5c

Fig 19

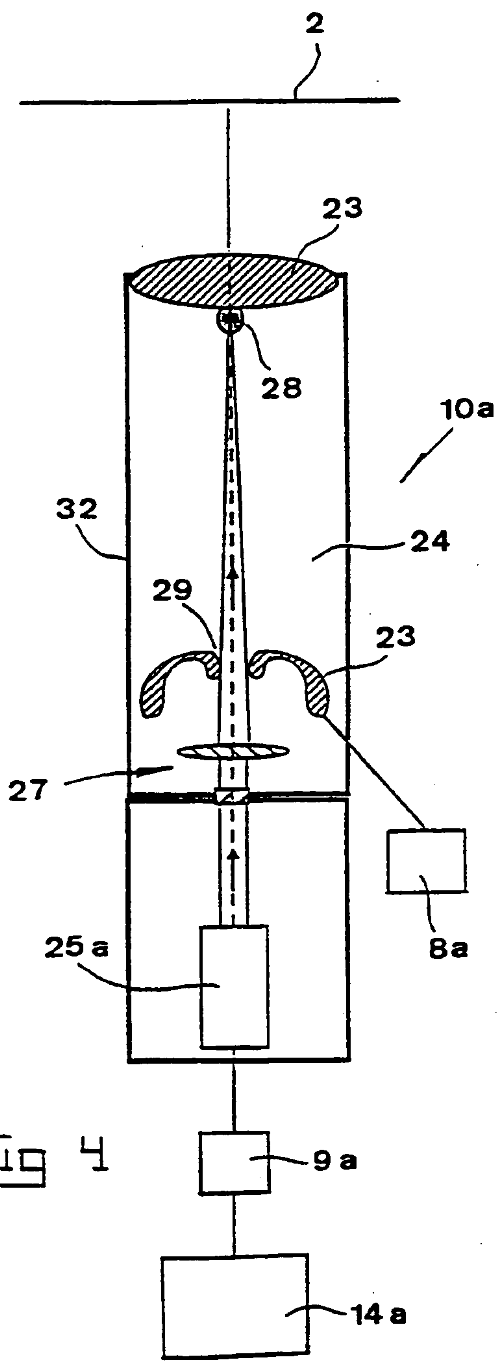



Fig 4

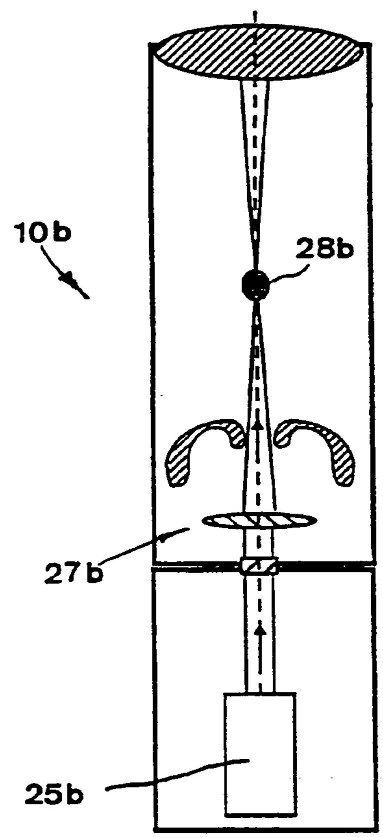



Fig 5

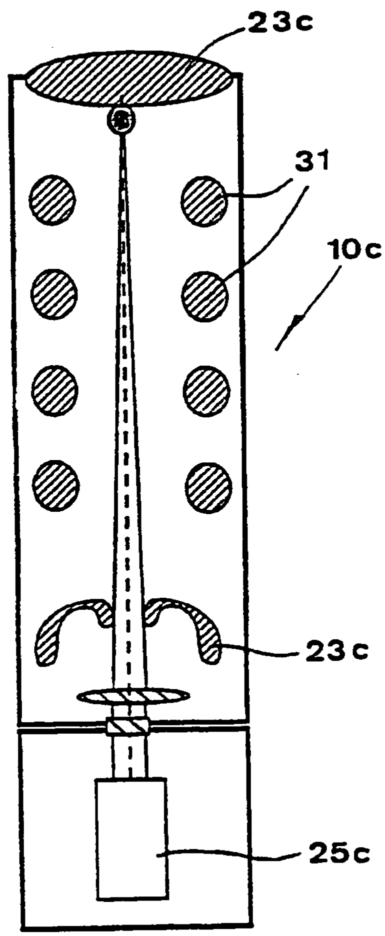



Fig 6

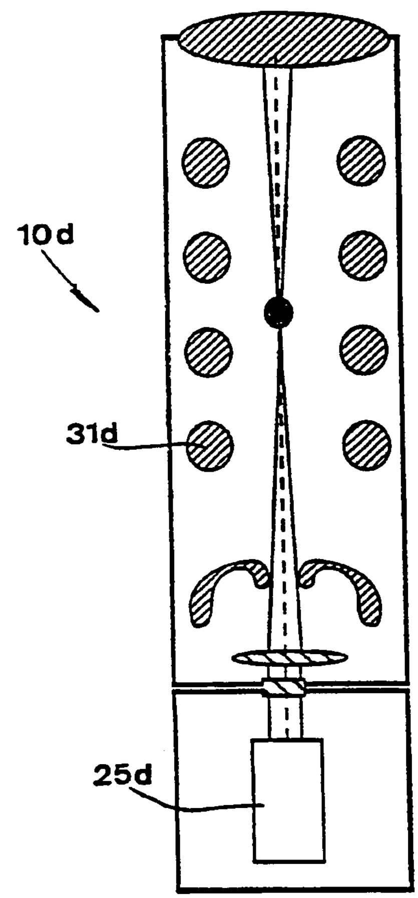



Fig 7

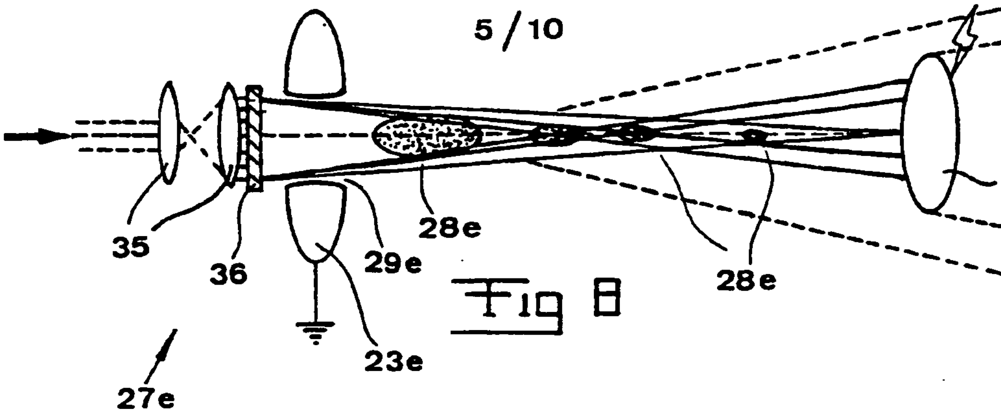



Fig 8

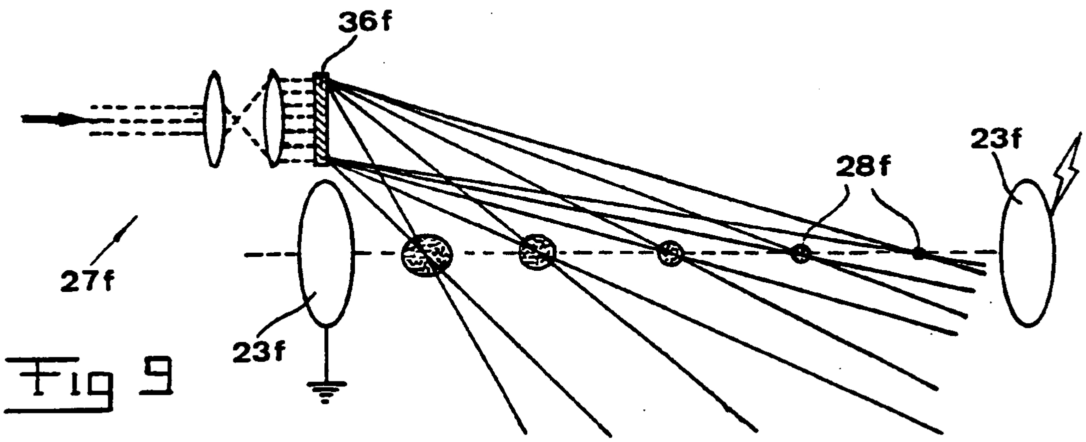



Fig 9

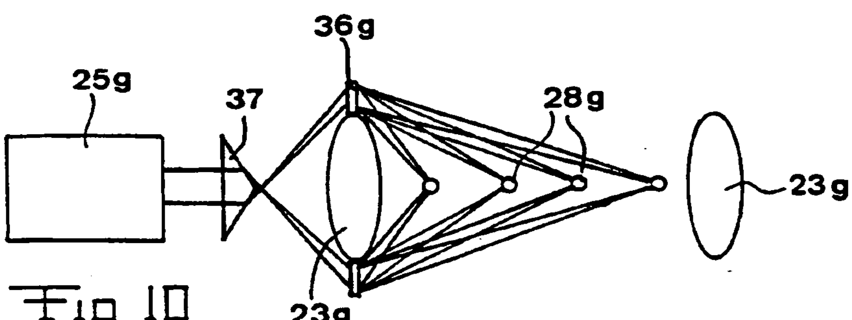



Fig 10

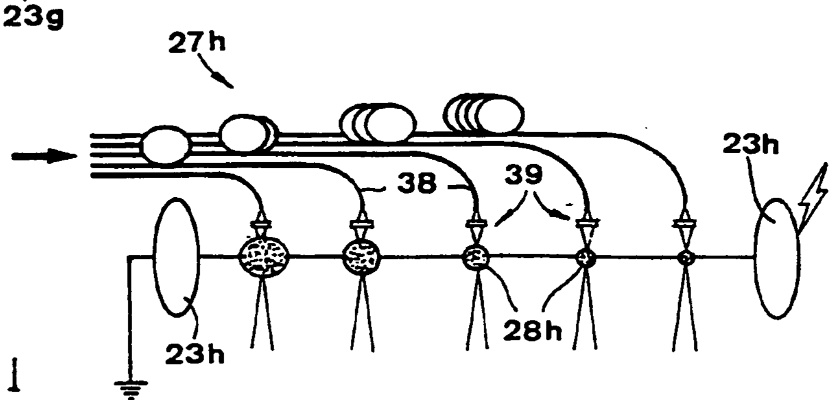



Fig 11

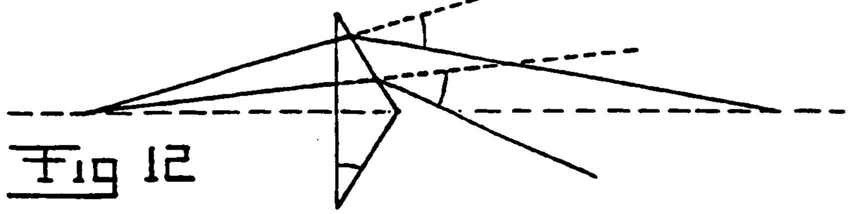


Fig 12

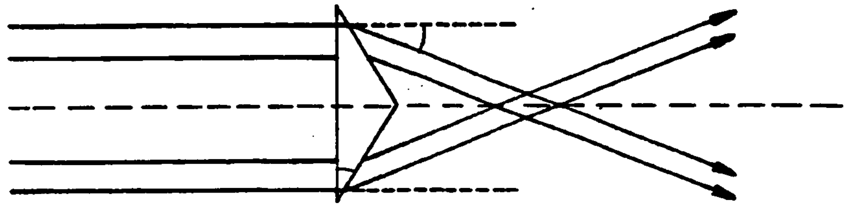


Fig 13

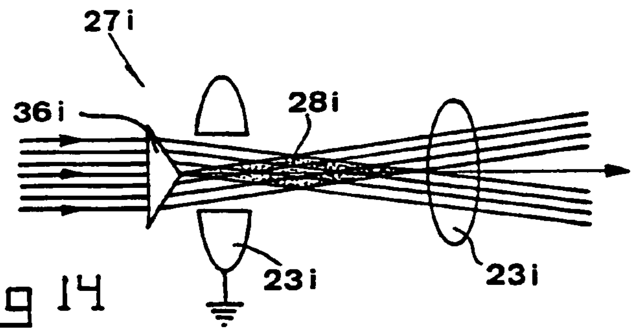



Fig 14

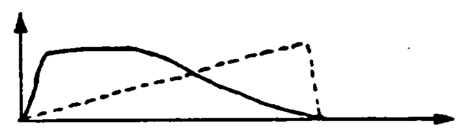
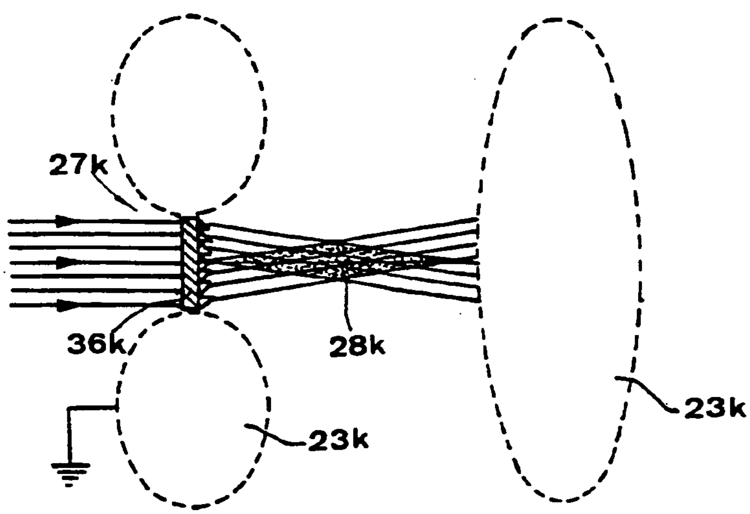


Fig 15



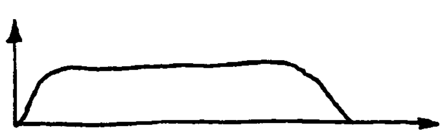



Fig 16

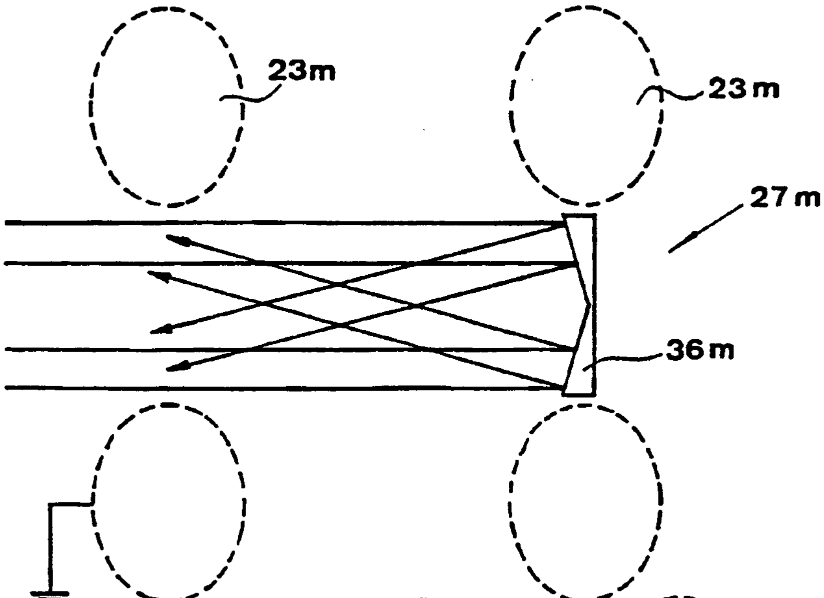



Fig 17

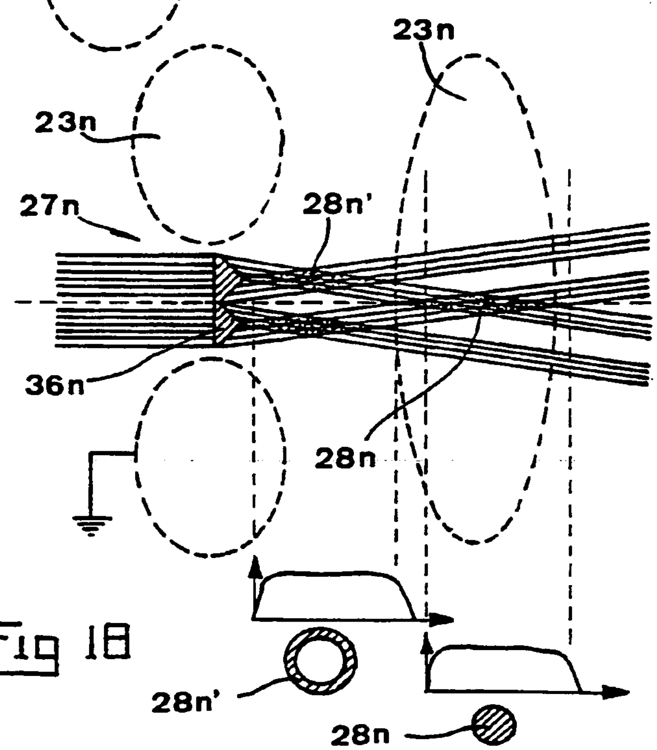



Fig 18

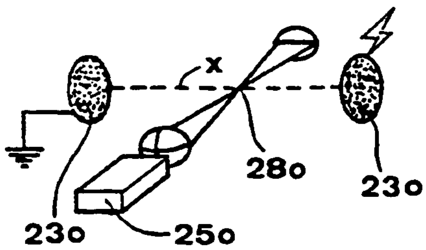



Fig 20a

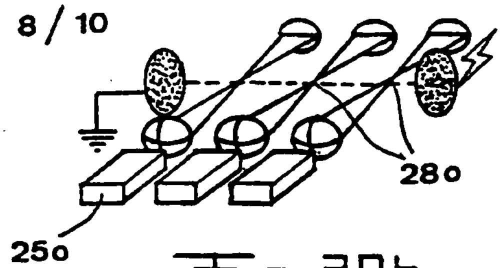



Fig 20b

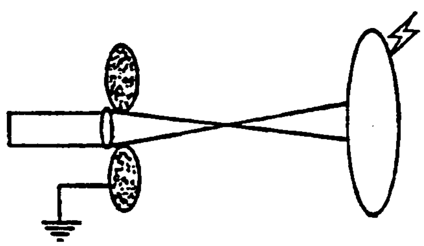


Fig 21a

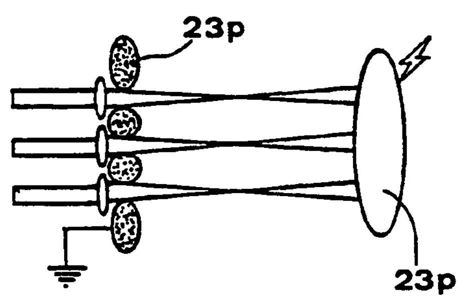



Fig 21b

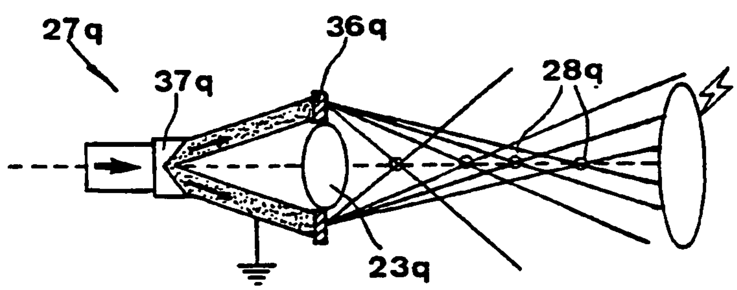



Fig 22

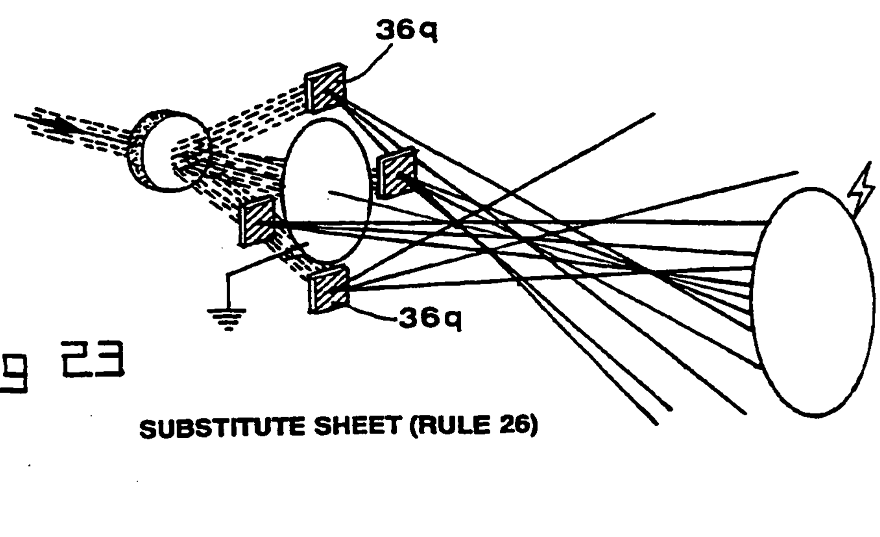



Fig 23

Fig 24

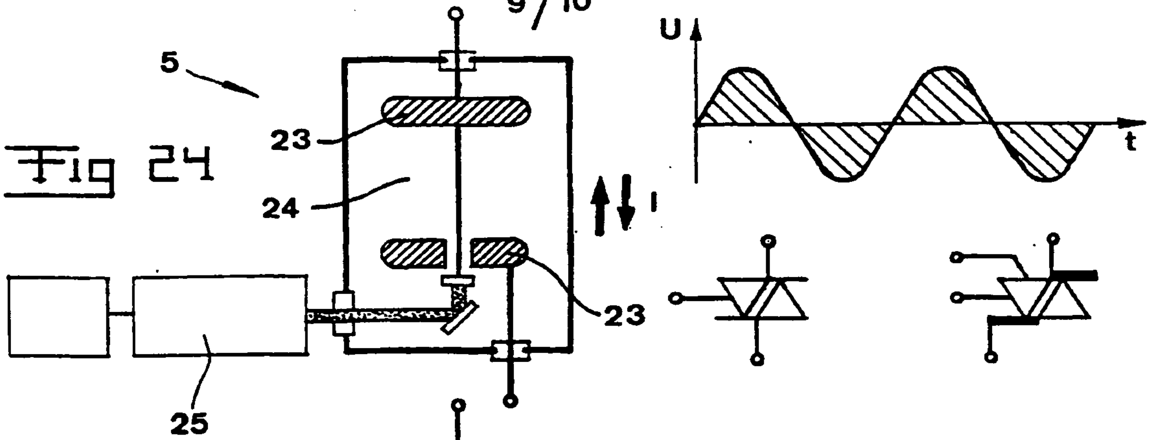



Fig 25

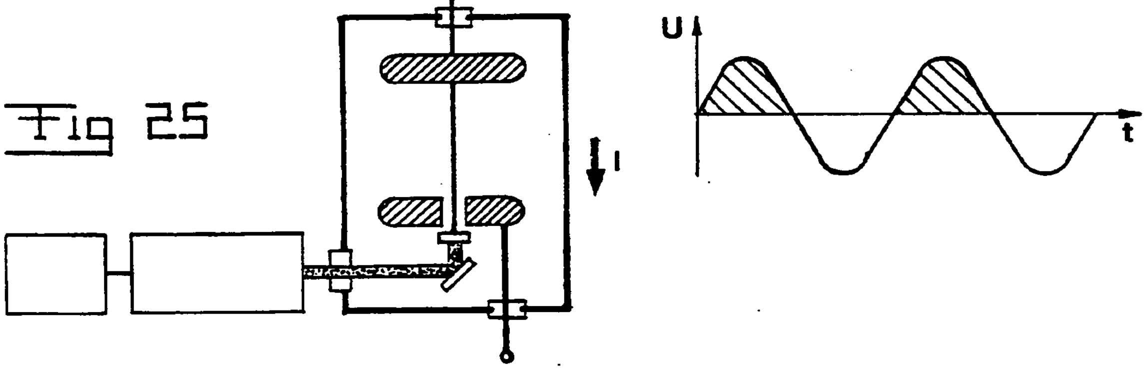



Fig 26

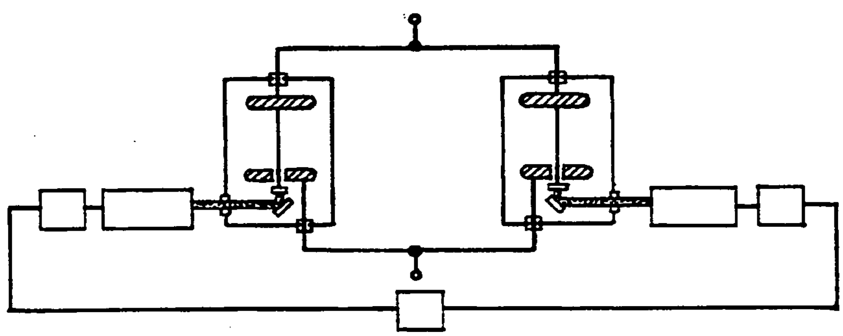


Fig 27

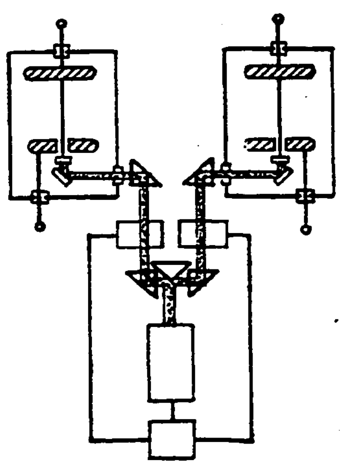


Fig 28

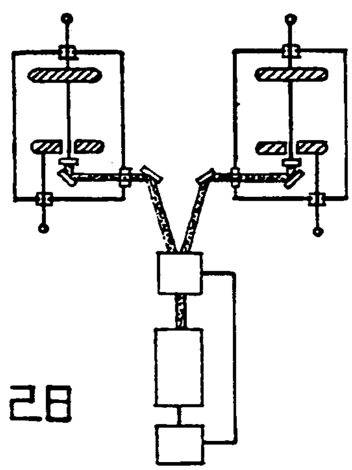


Fig 29a

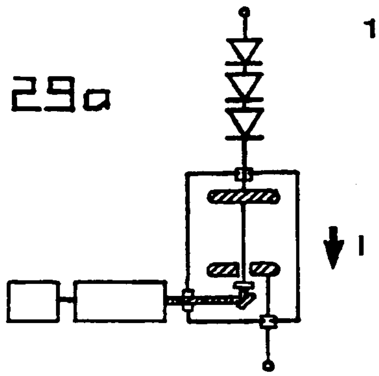
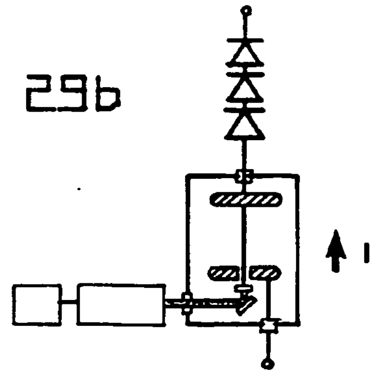



Fig 29b



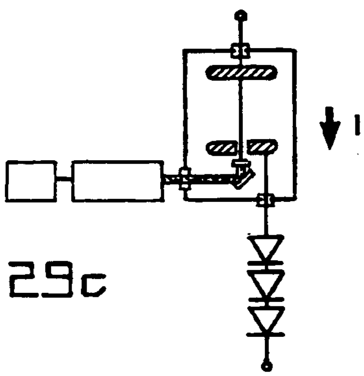




Fig 29c

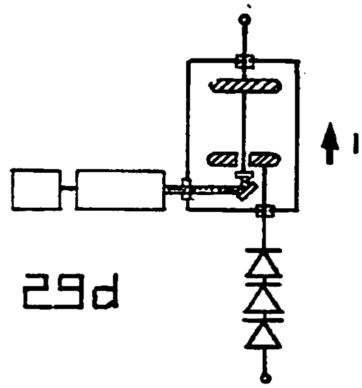
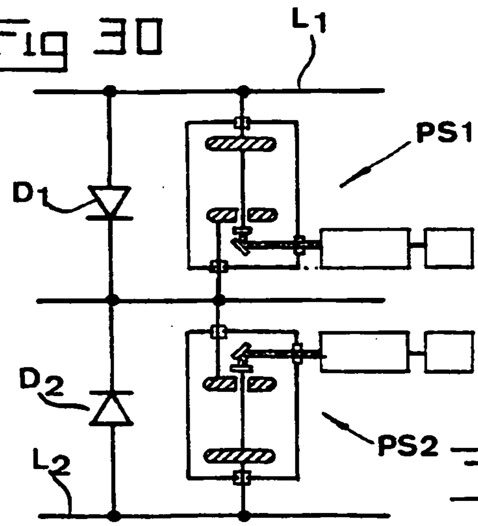



Fig 29d

Fig 30



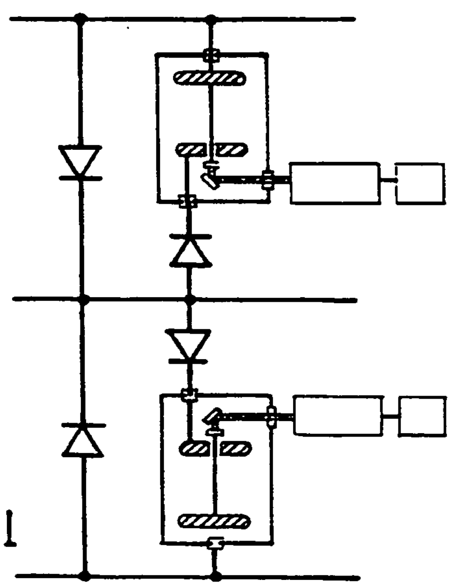



Fig 31

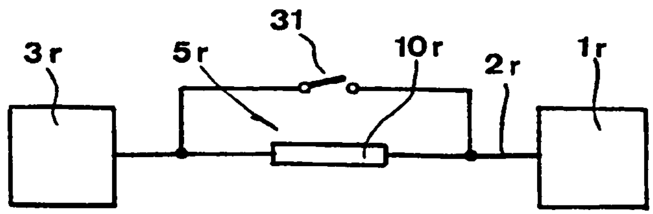



Fig 32

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# INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)


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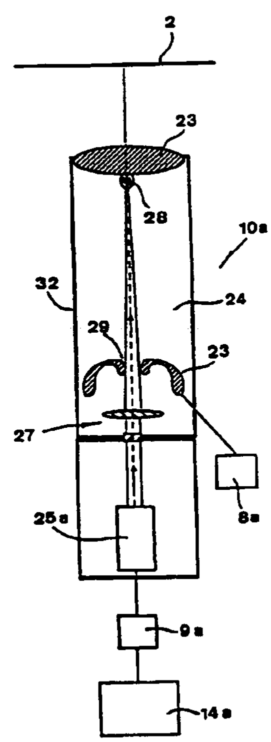
(54) Title: SWITCHING DEVICE INCLUDING SPARK GAP FOR SWITCHING ELECTRICAL POWER, A METHOD FOR PROTECTION OF AN ELECTRIC OBJECT AND ITS USE


(57) Abstract

A device for switching electric power comprises at least one electric switching arrangement (5). This switching arrangement comprises at least one switching element (10a) comprising an electrode gap (24). This gap is convertible between an electrically substantially insulating state and an electrically conducting state. Furthermore, the switching element comprises means (25) for causing or at least initiating the electrode gap or at least a part thereof to assume electrical conductivity. The means (25) for causing or at least initiating the electrode gap to assume conductivity are adapted to supply energy to the electrode gap in the form of radiation energy to bring the gap or at least a part thereof to the form of a plasma by means of this radiation energy.

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International application No.
PCT/SE 97/02153

## A. CLASSIFICATION OF SUBJECT MATTER

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| Y | column 1, line 10 - line 15; column 3, line 8 - line 28, ; column 3, line 39 - line 55; column 4, line 20 - line 35; col. 4, line 46 - line 54, figures 2-5 | 7,9,30-33, 40-46,50-51 |
| | -- | |
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| Y | column 1, line 10 - line 12; column 2, line 35 - line 43, ; column 3, line 18 - line 29; column 4, line 28 - line 51 | 7,9,30-33, 40-46,50-51 |
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International application No.
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| Y | column 1, line 14 - line 31; column 1, line 47 - line 54, ;col. 2, line 21 -line 29, col . 2, line 47 - line 57; col. 3, line 36 - line 42, line 49- line60, fig 2 | 7,9,30-33, 40-46,50-51 |
| | -- | |
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| Y | column 2, line 10 - line 16; column 2, line 26 - line 38, ; col. 4, line 21 -line 30; col.5, line 7 - line 14, line 32- line 44; col. 6, line 41 - line 46, figure 11 | 7,9,30-33, 40-46,50-51 |
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| A | US 4134146 A1 (E.W. STETSON), 9 January 1979 (09.01.79), column 1, line 1 - line 14 | 29 |
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| US 4978893 A1 | 18/12/90 | NONE | |
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